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Forest Pest
Management

Davis, CA.

SPRAY ACCOUNTANCY REVIEW - A LITERATURE SEARCH

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Spray Accountancy Review - A Literature Search

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APPENDIX

VII

TRIAL RECORD DPGTR 324
HIGH ALTITUDE RELEASE BIS
SPRAY TRIALS WITH THE E29R1
SPRAY TANK, C 607

Chemical Branch
Test Design and Analysis Office
Technical Plans and Evaluation Directorate
January 1963

U.S. Army
Test and Evaluation Command
Dugway Proving Ground
Dugway, Utah

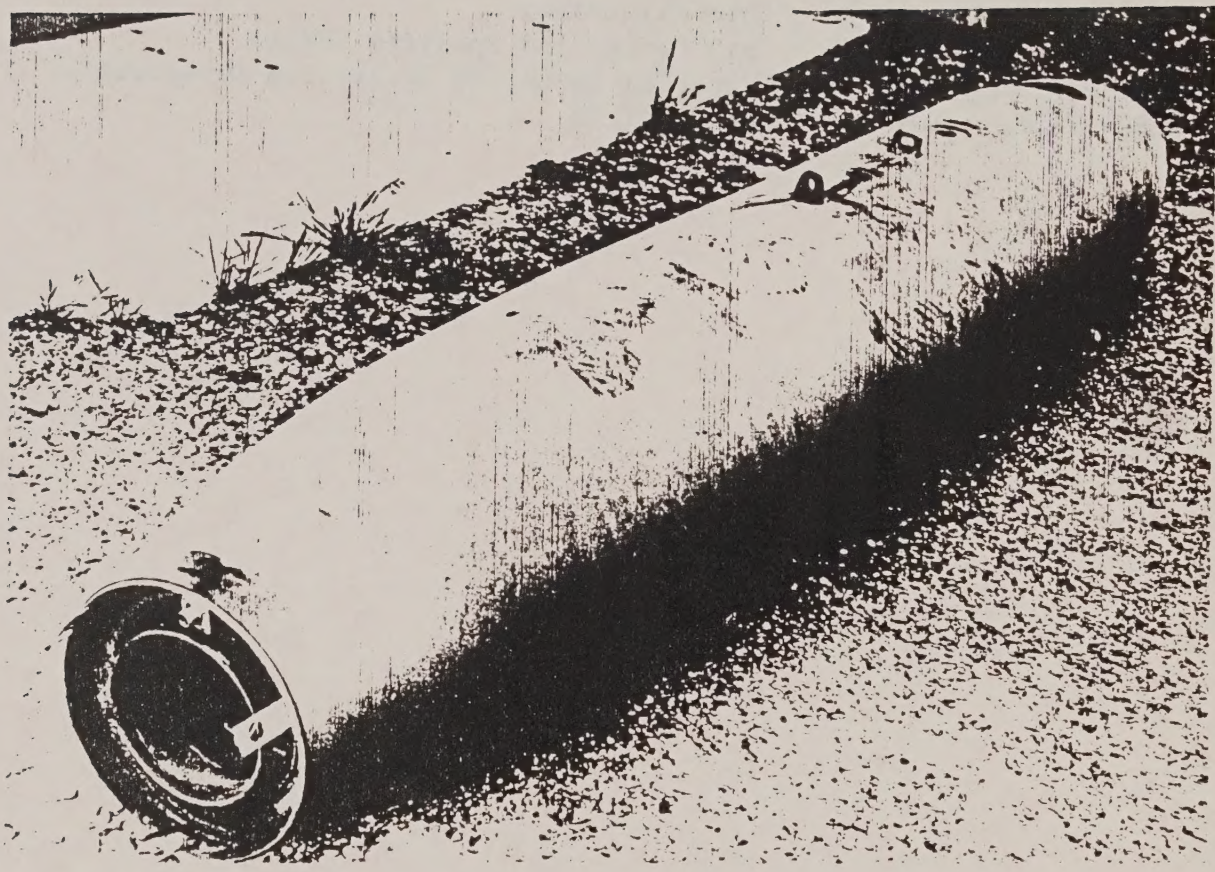

Figure 3 Rear view of E29R1 spray tank used on C 607

B. Agent: In each trial, each spray tank was filled with approximately 730 pounds of V-agent simulant (Bis 2-ethylhexyl hydrogen phosphite). The Bis fill was dyed with 6 grams of DuPont Oil Red (C.I. 258) per liter of agent. A control sample from the agent lot number used to fill the spray tanks on each trial was sent to the Analytical Laboratory, DPG, for use in the preparation of standards for the analytical assay of each trial.

C. Aircraft: One F-100 type jet aircraft was to be used on all trials as the support vehicle for the spray tanks. One L-19 aircraft was used to provide planesonde data on all trials.

D. Grid Layout and Flight Procedures: In C 607, the grid was designed to contain agent clouds carried by winds from a southeasterly (100-180°) direction was indicated in Figure 4. Four flight lines were

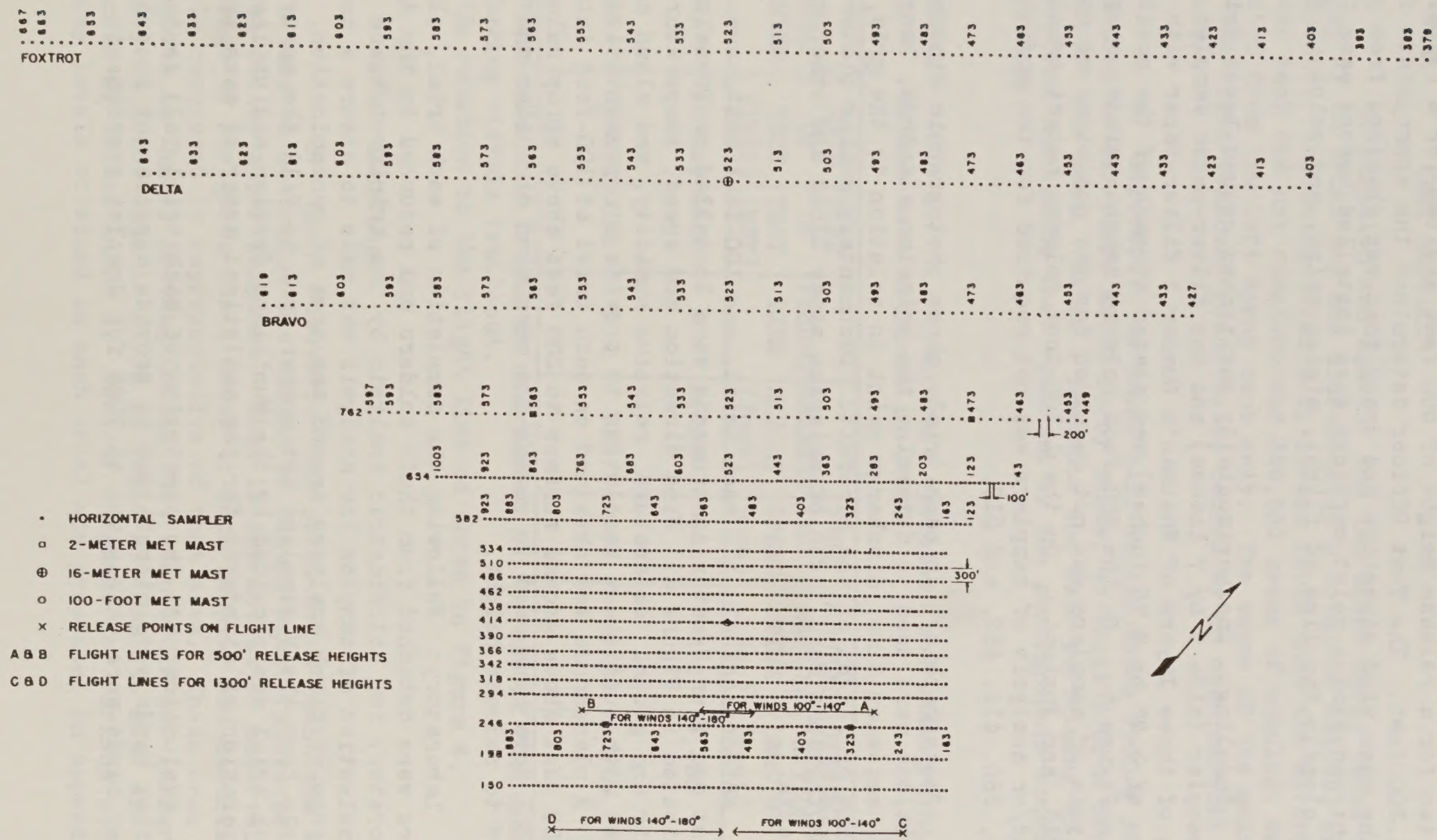

Figure 4 Grid array for C 607

available; two for a release height of 500 feet and two for a release height of 1,300 feet. The Test Officer determined the appropriate flight line from the mean wind direction and speed that was obtained from pibal data. Flight and aiming point markings were installed before each trial to indicate clearly the line of flight, aiming point, and point of discharge.

E. Sampling: One horizontally positioned ground level Printflex-card sampler (size 6 by 7 inches) and one filter-paper sampler (consisting of three layers of Whatman's Number 1 filter-paper with an exposed area of 3.25 by 7.75 inches) was placed at each of the positions indicated in Figure 4. On the 500-foot release height trials, sampling and/or analysis of samplers was not required for the positions of rows 150, 198, 246, and Foxtrot. On the 1,300-foot release height trials, sampling and/or analysis of samplers was not required for the positions of rows 318, 366, 414, 462, and 510.

F. Photographic: In each trial, three photographic cinetheodolite positions were used to determine the emission altitude, length of emission, emission time, discharge point in relation to the grid, and speed and line of flight of the aircraft. Documentary motion pictures and still photographs were taken of emission spray lines and other operational subjects.

G. Meteorological: In each trial, one 100-foot mast, one 16-meter mast and four 2-meter instruments were installed on Downwind Grid as indicated in Figure 4. Wind direction and speed, temperature gradient, air and ground temperature, relative humidity, and cloud cover were measured with sufficient resolution to provide a representative wind track. A planesonde was obtained on each trial at 100-foot intervals from 100 feet above ground surface to 200 feet above spray release height. Pibal data were used to obtain the mean wind direction and speed from surface to release height.

H. Laboratory: Following the completion of each trial, all filter papers were detached from their holders and returned to the Analytical Laboratory for colorimetric analysis by the trinitrobenzene method. A selection of samples for analysis was made to assure a one-position fringe of blank analyses around the area of contamination. A control sample from the V-simulant lot number used to fill the spray tanks on each trial was provided by the Munitions Section and utilized for the preparation of standards for the analytical assay of each trial.

I. Evaluation: At the conclusion of each trial, all contaminated Printflex cards were microfilmed to provide a permanent record. The Printflex cards were then given to TD&A for droplet assessment.

VII. TEST RESULTS:

A. Munition and Agent: The two E29R1 spray tanks functioned properly in Trial A-1 and disseminated a total of 631,851 grams of simulant. Following Trial A-2, it was found that the aircraft's right spray tank did not function and 326,585 grams of simulant was disseminated from the left spray tank only. The cause of the malfunction of the right tank was found to be caused by an open circuit in the aircraft.

B. Aircraft: On Trial A-1, an Air Force F100-F jet aircraft was used to carry the E29R1 spray tanks; on Trial A-2, a Navy FJ4B jet aircraft was used. Table 1 presents the data pertaining to aircraft operation, including that recorded by the photographic cinetheodolite positions.

Table 1 Aircraft operation and photographic cinetheodolite data obtained in C 607

TRIAL NUMBER	DATE OF TEST (1961)	TIME OF TEST (MST)	FLIGHT LINE	RELEASE HEIGHT (Feet)	TRUE AIR-SPEED (mph)	DISSEMI-NATION TIME (Sec)	DISSEMI-NATION LENGTH* (Feet)	LOCATION OF AIRCRAFT** (Feet)
A-1	15 Aug	0535	D	1,380	443	8.2	5,330	1,400 late 120 left
A-2	1 Nov	0751	B	710	407	10.4	6,210	380 early 110 left

*Dissemination length is calculated at the end of dissemination including visible trail-out.

**In relation to the flight line as shown in Figure 4.

C. Sampling:

1. Agent Recovery: The point-count technique was used in all trials to determine the amount of liquid agent recovered by the horizontal filter-paper samplers. This is the method of ascertaining area coverage by assigning fixed areas to each sampler and assuming that the sample recovered is representative of that area. These area assignments are given in Dugway Proving Ground Test Plan DPGTP 607 (Reference A). A summary of these data is given in Table 2; complete data are presented in Appendix A, Tables 1 and 2. Contour diagrams for various contamination density levels obtained in each trial are presented in Appendix B.

Table 2 Liquid agent recovery data for C 607

TRIAL NUMBER	AMOUNT OF AGENT DISSEMINATED (gm)	AMOUNT OF AGENT RECOVERY (gm)	ESTIMATED AGENT RECOVERY (%)
A-1	631,851	415,149	65.7
A-2	326,585	250,917	76.8

2. Area Coverage: Area Coverages, in square meters, for various contamination density levels obtained in each trial are presented in Table 3.

Table 3 Area Coverage in square meters obtained at ground level with the Bis-filled E29R1 spray tank in C 607

CONTAMINATION DENSITY (mg/m^2)	AREA COVERAGE (Square Meters) FOR INDICATED TRIALS	
	A-1	A-2
≥5	4,603,274	5,590,165
≥10	4,239,637	4,242,929
≥50	3,053,623	1,036,764
≥100	1,738,637	551,268
≥500	-*	16,722
RELEASE HEIGHT-WIND SPEED PRODUCT** (ft/mph)	25,944	14,342

*No data recorded.

**Data obtained by multiplying release height by the calculated mean wind speed.

3. Droplet: Only a limited number of horizontal Printflex cards were processed for each trial in order to calculate the mean wind speed between the release height and ground level, and to determine the droplet size spectra.

The procedure followed in calculating the mean wind speed is explained in detail in Appendix A, Paragraph II, B of DPGR 247[1] except on the present

[1]Technical Report DPGR 247. Comparative Trials Of The Modified And Unmodified Aero 14B Spray Tank, Bis-filled ____ Dugway Proving Ground, Dugway, Utah. April 1960.

trials the average stain diameter was weighted for contamination density at the position of stain. The results from these calculations are shown in Table 4, Section VII, Paragraph D of this report.

The procedure followed in determining the droplet size spectra is explained in Appendix A, Paragraph I of DPGR 247 except the average stain diameter was weighted once for contamination density at the position of stain, and again for affiliated total row contamination density. The weighting for contamination density of the affiliated row total has the effect of describing the mass-drop diameter spectrum most precisely around the mass median diameter and least accurately in the ranges of the smallest and largest drop sizes. The results obtained are shown in Figures 5 and 6.

The stain size data obtained for these trials may be found in Appendix C, Tables 1 and 2. Microfilm negatives of the contaminated Printflex cards obtained on these trials are on file at DPG, and prints of these negatives are available upon request.

D. Meteorological: Table 4 presents a summary of the general meteorological conditions existing at or near release time in each trial. Complete meteorological data are presented in Appendix D.

Table 4 General meteorological conditions for C 607

TRIAL NUMBER	2-METER WIND		100-FOOT WIND		2-METER AIR TEMPERATURE (°F)
	Direction (°)	Speed (mph)	Direction (°)	Speed (mph)	
A-1	163	3.3	144	16.6	66.7
A-2	183	8.3	189	13.1	35.9

(Continued)

Table 4 (Concluded).

TRIAL NUMBER	2-METER RELATIVE HUMIDITY (%)	TEMPERATURE GRADIENT (F°)	CALCULATED MEAN WIND (mph)
		0.5 to 16.0 m	
A-1	56	5.8	18.8
A-2	85	0.3	20.0

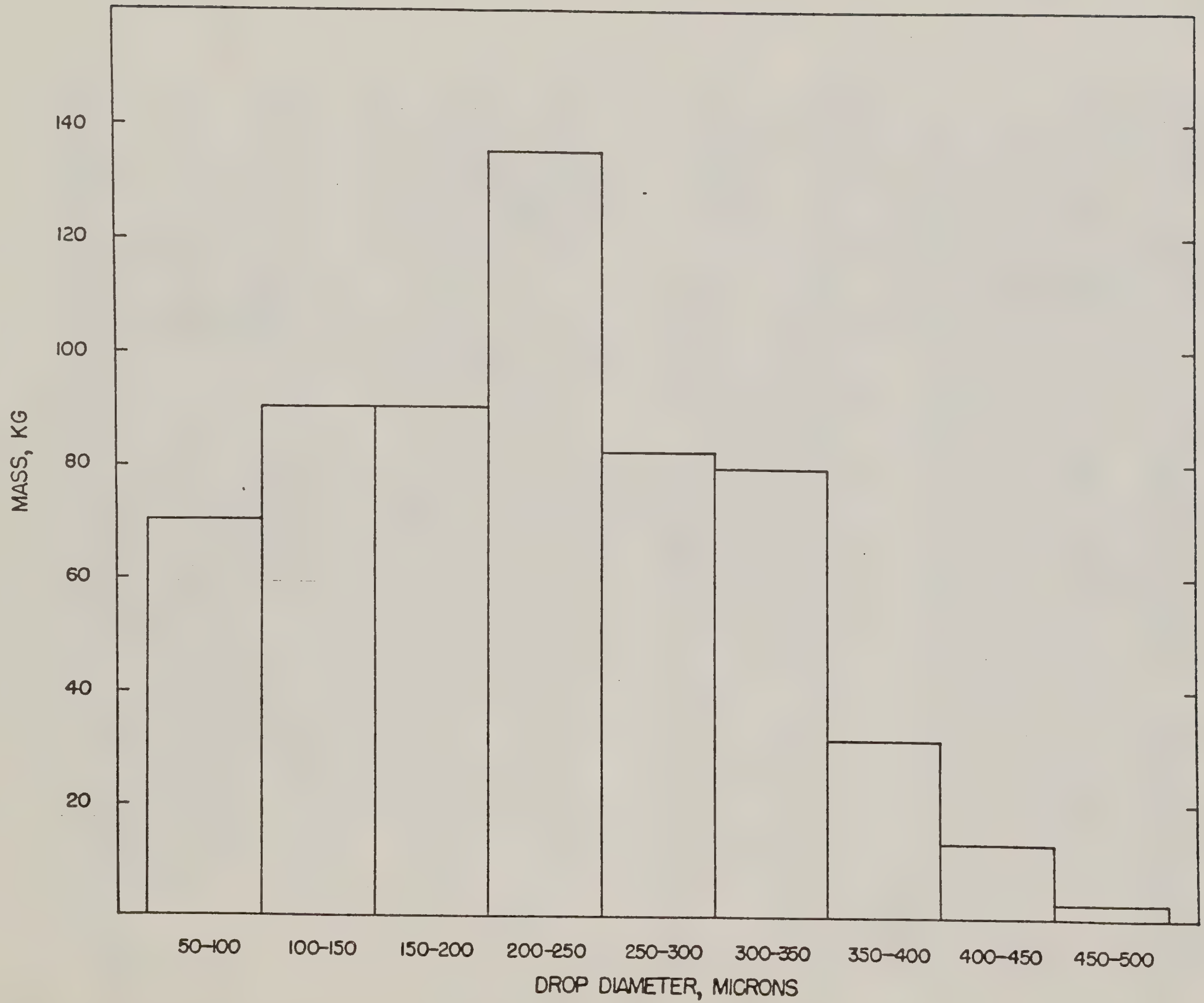

Figure 5 Apparent mass-drop diameter spectra for C 607, Trial A-1

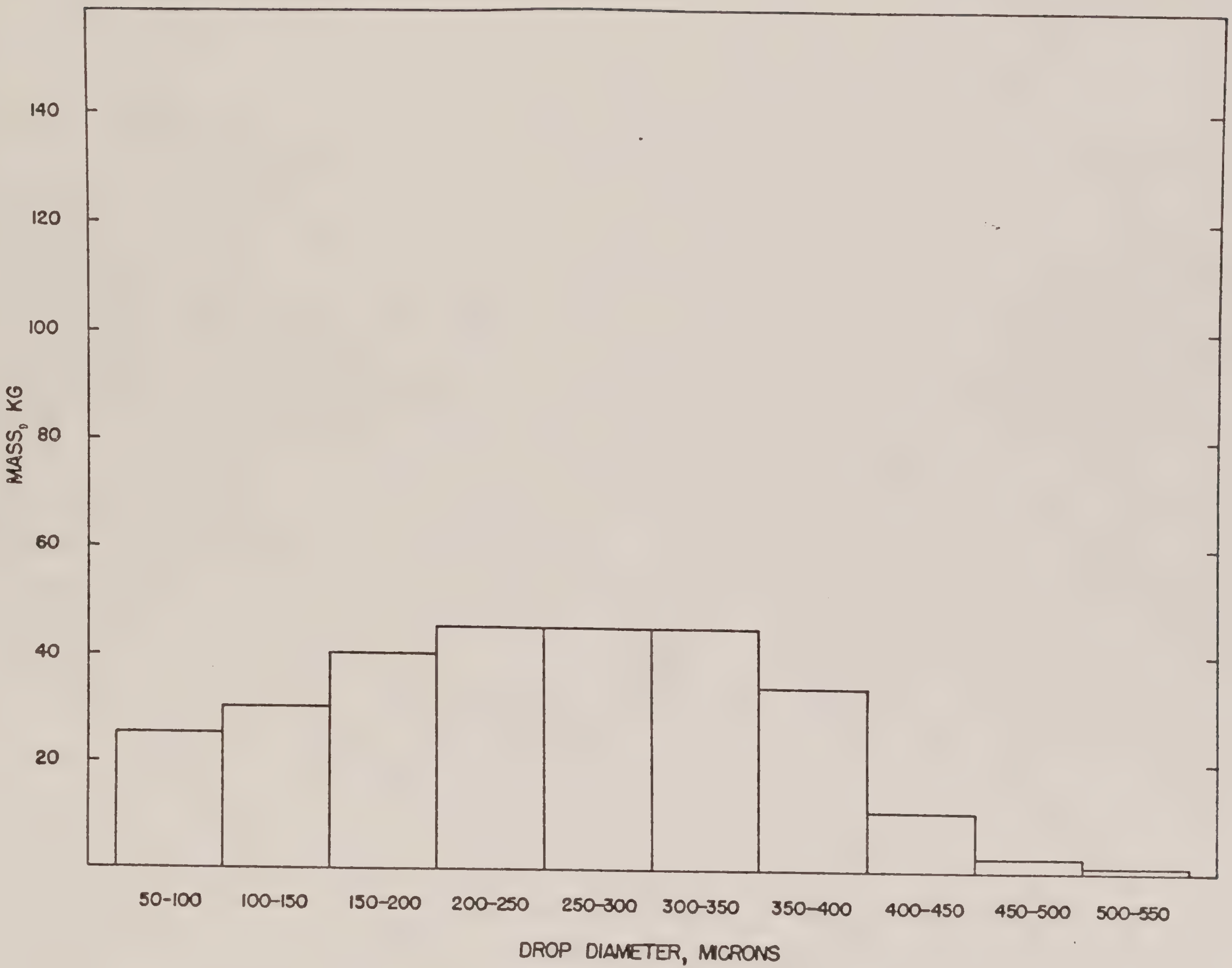

Figure 6 Apparent mass-drop diameter spectra for C 607, Trial A-2

APPENDIX

VIII

Item 8

DPGR 247

AD No. 343004

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APRIL 1960

COMPARATIVE TRIALS OF THE MODIFIED AND UNMODIFIED AERO 14B SPRAY TANK, BIS-FILLED

U.S. ARMY CHEMICAL CORPS PROVING GROUND

DUGWAY PROVING GROUND

DUGWAY, UTAH

DPGR/TR 247

343004

MATERIALS AND METHODS

MATERIALS

Munitions

The munition used in these trials was the U.S. Navy Aero 14B Spray Tank. Phase A trials required the use of the modified tank and Phase B required the use of the unmodified tank. The unmodified Aero 14B Spray Tank contains an 1800 psi nitrogen gas reservoir, a pressure regulator to reduce the pressure to 100 psig, an agent reservoir, a pneumatically operated discharge valve, and a spear discharge nozzle (no diffuser cone was used). The modified Aero 14B Spray Tank differs only in that the discharge tube and spear valve aft of the discharge valve were removed and replaced by a discharge tube containing straightening vanes and a contoured nozzle designed to convert the spray system from a producer of fine aerosols to a producer of larger droplets. This tank was modified by Edo Corporation personnel through arrangements made by Chemical Warfare Laboratories, Army Chemical Center, Maryland (CWL). The agent capacity is approximately 91.5 gallons; suspension lug spacing is 30 inches.

Agent

On each trial the spray tank was filled with approximately 700 pounds (317,513 grams) of the V-agent simulant Bis (bis 2-ethyl hexyl hydrogen phosphite). The agent fill was dyed with 6 grams of DuPont Oil Red dye (C.I. 258) per liter of agent. The dyeing and filling were accomplished at the U.S. Army Chemical Corps Proving Ground, Dugway, Utah.

Aircraft

One Marine A4D aircraft was used on all trials as the support vehicle for the spray tank. One L-19 aircraft was used to provide planesonde data on all trials except Trial B-3. Because of an operational oversight the plane was not used on this trial.

Grid Location

All trials were conducted on Downwind Grid, Dugway Proving Ground, Utah, a permanent grid located 11 miles southwest of Dog Area (Fig. 1).

Fig. 1.- Aerial view of Downwind Grid.

Grid Layout

In CW 442, the grid was designed to contain agent clouds carried by winds from either a northwesterly (280-360°) or from a southeasterly (100-180°) direction (Fig. 2).

Sampling Layout

Horizontal Samplers

Horizontally-positioned ground-level filter-paper samplers and Printflex-card samplers were attached to steel plate holders as shown in Figure 3 and placed at positions as indicated in Figure 2. The filter-paper samplers consisted of three layers of Whatman's Number 1 filter paper, and had an exposed area 3.25 by 7.75 inches in size. The Printflex-card samplers had an exposed area of 7 by 6 inches.

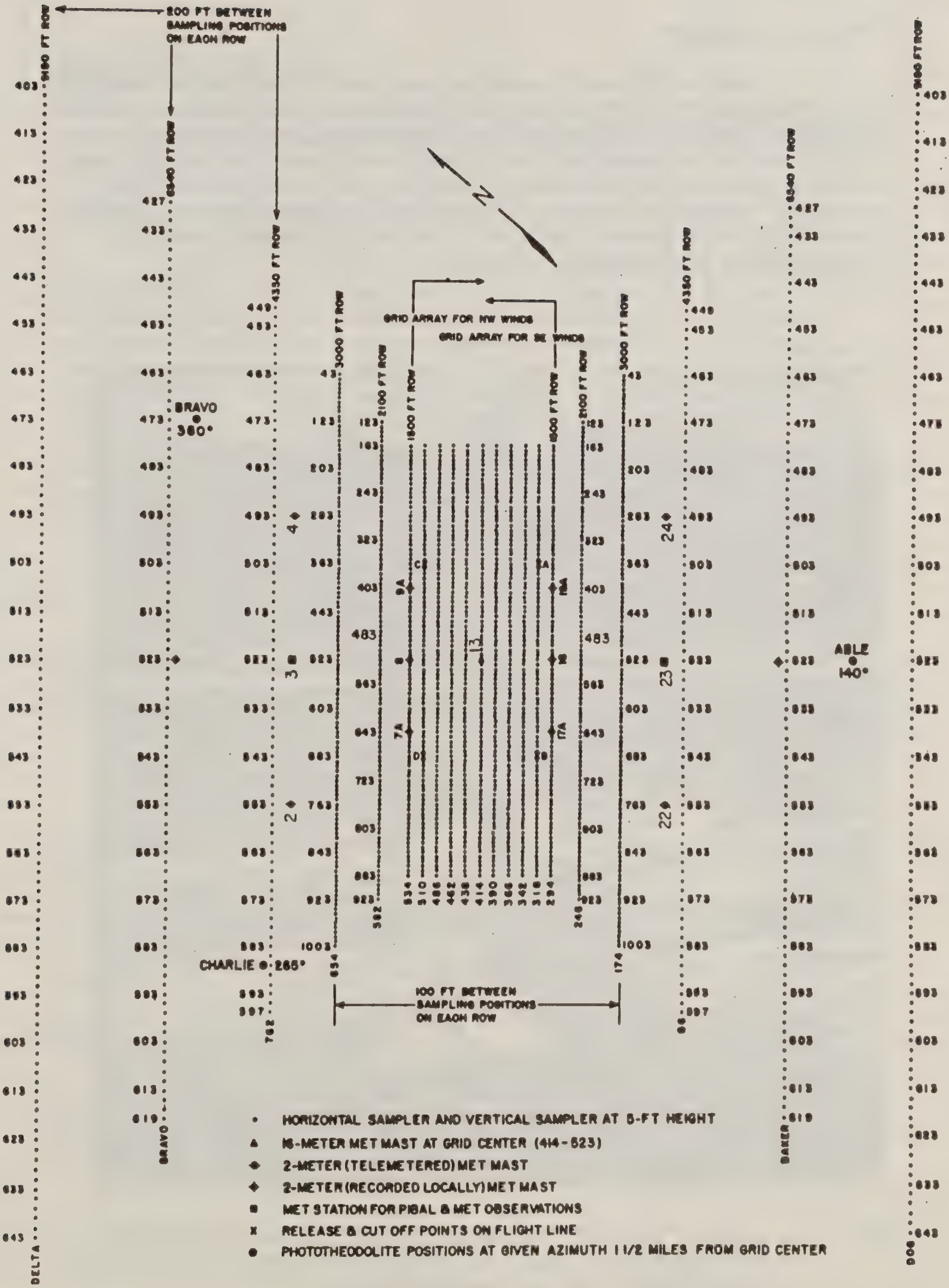

Fig. 2.- Overall grid diagram for CW 442 Spray Trials.

Vertical Samplers

Vertically-positioned cylindrical filter-paper samplers and Printflex-card samplers were wrapped around vertically-positioned cylinders 2.69 inches in diameter and 3.75 inches in height and were placed at the 5-foot level as shown in Figure 3 and at positions as indicated in Figure 2. The filter-paper samplers consisted of three layers of Whatman's Number 1 filter paper 3.75 by 8 inches in size. The Printflex-card samplers were 3.75 by 6.75 inches in size.

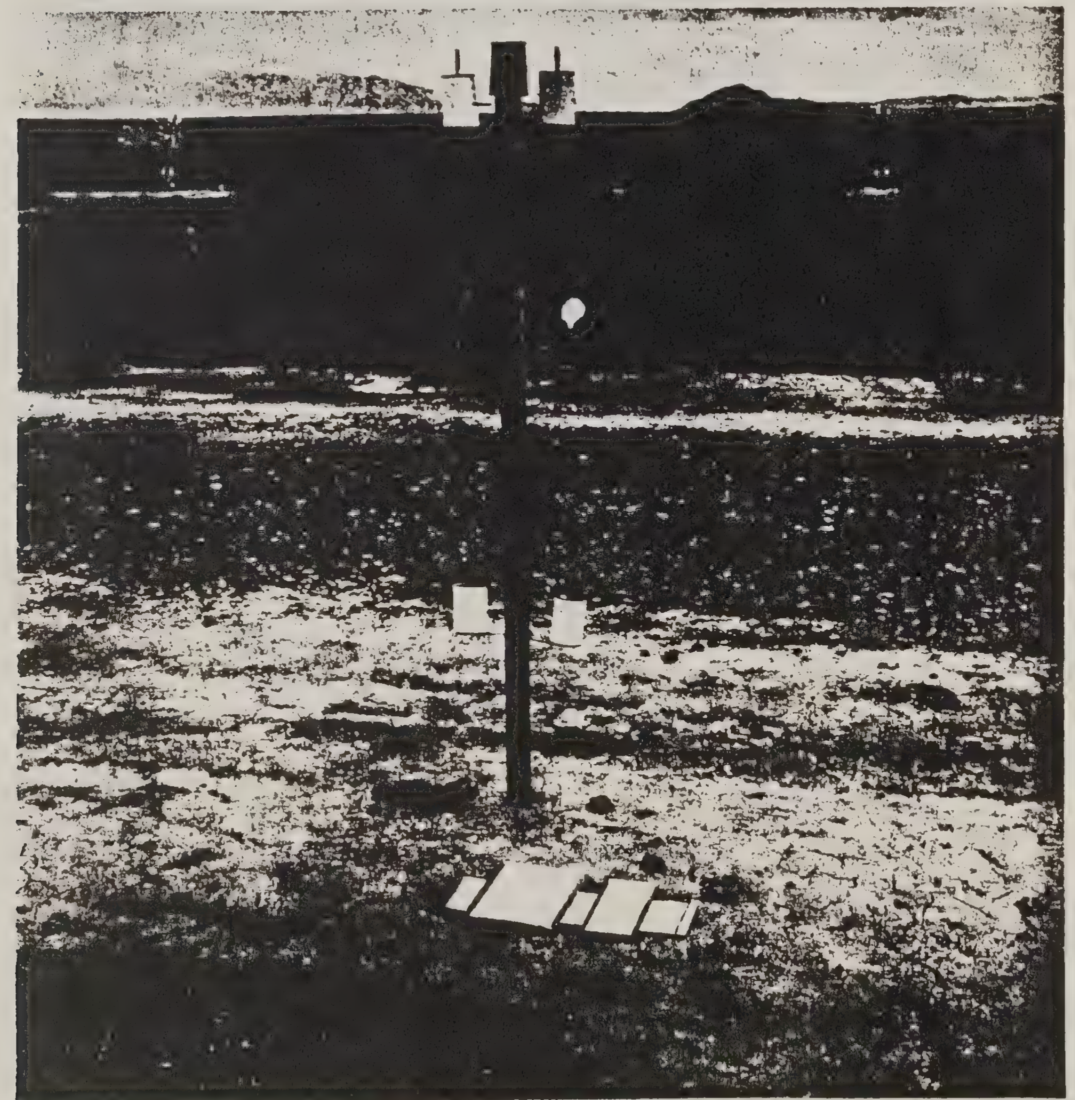

Fig. 3.- Typical sampling station showing horizontal and vertical samplers at 1.5- and 5-foot intervals (the 1.5-foot position was not used on CW 442).

Photographic Equipment

Three phototheodolites, one normal speed motion picture camera, one still camera, and one microfilm camera were used on the trials of CW 442.

Meteorological Equipment

On each trial six 2-meter anemometer and direction instruments and one 16-meter mast were installed to telemeter data to the Downwind Grid Command Post. In addition, one 2-meter anemometer and direction instrument (recorded locally), one meteorological station installed 2500 feet upwind of spray release line to obtain pibal and meteorological observation data, and planesonde equipment were employed on each trial, with the exception that on Trial B-3 an operational oversight prevented the use of the planesonde equipment. Table 1 gives the positions employed for trials having either a northwest or southeast wind (referenced positions are shown in Figure 2).

TABLE 1: Meteorological Positions Used on Trials Having a NW or a SE Wind Direction (UNCLASSIFIED)

WIND DIRECTION	2-METER TELEMETERED INSTRUMENT NUMBERS	2-METER LOCALLY RECORDED INSTRUMENT NAMES	16-METER PROFILE MAST NUMBER	PIBAL STATION NUMBER
NW	8, 17A, 18, 19A, 22, and 24	Baker	13	3
SE	18, 7A, 8, 9A, 2, and 4	Bravo	13	23

METHODS

Munition Procedures

On each trial, a single Bis-filled Aero 14B Spray Tank (modified or unmodified) was mounted under the fuselage of an A4D Marine jet aircraft. Each tank was weighed before and after each trial to determine the amount of agent disseminated.

Flight Procedures

On each trial, the Test Officer was responsible for determining the altitude at which the agent was released from the aircraft (approximately 100-300 feet) in order to obtain the desired product of release height and wind speed. The 16-meter wind speed was used as an approximate guide to determine this release height. The 16-meter wind direction was used by the Test Officer to determine the appropriate flight line to be used from information contained in Table 2. The desired true airspeed of the aircraft on all trials was approximately 450 mph.

TABLE 2: Distinct Flight Requirements for Two-directional Grid* (UNCLASSIFIED)

GRID SECTOR	CROSSWIND DIRECTION (°)	FLIGHT LINE	POINT OF DISCHARGE	AIRCRAFT HEADING (°)
SE Winds	110	C-B	C	200
	140	A-B	A	230
	170	A-D	A	260
NW Winds	290	C-B	C	200
	320	C-D	C	230
	350	A-D	A	260

*See Figure 2.

Photographic Procedures

In all trials the following data were obtained from the three phototheodolite positions (see Figure 2) located on the 1½-mile arc: release height, length of release, release time, discharge and cut-off points in relation to grid, and speed and line of flight of the aircraft.

At the conclusion of each trial, all contaminated Printflex cards were microfilmed to provide a permanent record. The Printflex cards were then given to Test Design and Analysis Office for droplet assessment.

Meteorological Procedures

Wind direction and speed, temperature gradient, air and ground temperature, relative humidity, and cloud cover were measured in accordance with DPG OPER-SOP-MET No. 11: "Meteorological Coverage and Data Schedule for Standard Tests,"[4] dated 24 October 1956. A planesonde was obtained at 50-foot intervals from 50 feet above ground surface to 100 feet above spray release height for each trial except Trial B-3. Pibal data were used to obtain the mean wind direction and speed from surface to release height.

Laboratory Procedures

At the conclusion of each trial, all filter papers were removed from the steel plate holders and were taken to the Analytical Laboratory where the agent was extracted from the filter papers and analyzed colorimetrically. A selection of samples for analysis was made to assure a one-position fringe of blank analyses around the area of contamination.

A control sample from the agent lot used to fill the spray tank on each trial was provided by Munitions Section and utilized in the analytical assay of each trial.

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[4]Published in the Appendix of Technical Report DPGR 235. Final Engineering Testing of the M121 Howitzer Shell, Volume II; Dissemination Phase (U). Dugway Proving Ground, Utah. December 1958. Confidential.

RESULTS

METEOROLOGICAL DATA

A summary of the general meteorological conditions existing at or near release time is given in Table 3; complete meteorological data can be found in Appendix D. The 2-meter and 16-meter wind speed and wind direction recorded for each trial were determined by averaging the wind speeds and wind directions from the 2-meter and 16-meter levels of the 16-meter profile mast (located in center of grid) for the interval between release time minus 1 minute to release time plus 1 minute.

TABLE 3: Summary of Meteorological Data for CW 442, Phases A and B

TRIAL NUMBER	DATE (1959)	SPRAY RELEASE TIME	2-METER WIND		16-METER WIND		CALCULATED MEAN WIND* (mph)
			Direction (°)	Speed (mph)	Direction (°)	Speed (mph)	
A-1	10 Jun	1828	356	5.4	348	7.7	10.1
A-2	12 Jun	0441	150	8.6	155	14.9	18.9
A-3	13 Aug	0547	345	1.5	341	5.1	11.6
B-1	10 Jun	0551	329	3.9	332	5.3	11.3
B-2	11 Jun	2029	135	2.7	088	7.2	14.1
B-3	11 Aug	0557	151	10.2	152	14.1	21.7
B-4	12 Aug	0558	164	11.5	172	18.4	16.2

*See Appendix A, Paragraph II B and Table 4.

Continued

TABLE 3: (Concluded)

TRIAL NUMBER	MEAN WIND**		AIR TEMPERATURE (°F)	TEMPERATURE GRADIENT (F°) 0.5 - 16.0 M
	Direction (°)	Speed (mph)		
A-1	348	11.6	75.1	- 0.1
A-2	158	12.9	62.0	3.8
A-3	353	5.1	58.7	3.0
B-1	332	12.5	50.9	- 0.5
B-2	084	13.9	71.5	10.2
B-3	156	22.1	75.2	0.5
B-4	158	14.0	68.5	0.0

**Mean wind from surface to release height obtained from pibal data.

MUNITION RESULTS

The amount of simulant disseminated on each trial was as follows: Trial A-1, 304,359 grams; Trial A-2, 294,380 grams; Trial A-3, 276,690 grams; Trial B-1, 297,101 grams; Trial B-2, 300,277 grams; Trial B-3, 286,215 grams; and Trial B-4, 275,329 grams.

PHOTOGRAPHIC RESULTS

The spray release data obtained on each trial by photographic methods are summarized in Table 4.

TABLE 4: Summary of Photographic Data Obtained on CW 442 (UNCLASSIFIED)

TRIAL NUMBER	RELEASE HEIGHT* (Feet)	AIRCRAFT SPEED (mph)	LENGTH OF DISSEMINATION** (Feet)	DISSEMINATION TIME (Sec)	FLIGHT LINE*3	POSITION OF DISSEMINATION LINE RELATIVE TO FLIGHT LINE
A-1	165	455	6000	9.0	A-D	On flight line, 310 feet early; 1030 ft late.
A-2	195	490	5590	7.8	A-B	On flight line, 70 feet early; 1420 ft late.
A-3	230	470	5350	7.8	C-D	25 feet left; 60 ft early; 1290 ft late.
B-1	300	460	5650	8.4	C-D	160 ft left; 50 ft early; 1600 ft late.
B-2	240	480	5820	8.3	C-B	50 ft right; 160 ft early; 1000 ft late.
B-3	230	475	5000	7.2	A-B	40 ft right; 350 ft early; 630 ft late.
B-4	65	480	4770	6.8	A-B	50 ft right; 370 ft early; 400 ft late.

*Data given for midpoint of dissemination line.
**End point includes calculation to point of visible trail-out.
*3See Figure 2 for referenced points.

FLIGHT RESULTS

The flight results pertaining to the portion of grid used, the flight of the plane, and the release height-wind speed product obtained on each trial are summarized in Table 5.

TABLE 5: Flight Data for CW 442*

TRIAL NUMBER	GRID SECTOR	CROSSWIND DIRECTION (°)	FLIGHT LINE	AIRCRAFT HEADING (°)	RELEASE HEIGHT-WIND SPEED PRODUCT** (ft/mph)
A-1	NW Winds	350	A-D	260	1667
A-2	SE Winds	140	A-B	230	3686
A-3	NW Winds	320	C-D	230	2668
B-1	NW Winds	320	C-D	230	3390
B-2	SE Winds	110	C-B	200	3384
B-3	SE Winds	140	A-B	230	4991
B-4	SE Winds	140	A-B	230	1053

*See Figure 2.
**Data obtained by multiplying release height by the calculated mean wind speed.

SAMPLING RESULTS

Horizontal Samplers

The point-count technique was used in all trials to determine the amount of liquid agent recovered. This is the method of ascertaining area coverage by assigning fixed areas to each sampler and assuming that the sample recovered by each sampler is representive of that area. A summary of these data is given in Table 6; complete data are presented in Appendix C, Tables 1 through 7.

TABLE 6: Liquid Agent Recovery Data for CW 442

TRIAL NUMBER	AMOUNT OF AGENT DISSEMINATED (Gm)	AMOUNT OF AGENT RECOVERY (Gm)	ESTIMATED AGENT RECOVERY (%)
A-1	303,359	262,133	86.1
A-2	294,380	232,028	78.8
A-3	276,690	202,031	73.0
B-1	297,101	223,222	75.1
B-2	300,277	198,105	66.0
B-3	286,215	219,952	76.8
B-4	275,329	216,457	78.6

Only a limited number of horizontal Printflex cards were processed for each trial in order to determine the droplet size spectra. The procedure followed is explained in detail in Appendix A, and the data obtained may be found in Appendix C, Tables 15 through 21. Microfilm negatives of the contaminated Printflex cards obtained on these trials are on file at Dugway Proving Ground and prints of these negatives are available upon request.

Contour diagrams for various contamination density levels obtained in each trial are presented in Appendix B.

Vertical Samplers

The data collected with the use of the cylindrical filter-paper samplers are presented in micrograms of agent per sampler in Appendix C, Tables 8 through 14.

No attempt has been made to obtain droplet size spectra collected by the cylindrical Printflex-card samplers. Microfilm negatives of the contaminated Printflex cards obtained on these trials are on file at Dugway Proving Ground and prints of these negatives are available upon request.

AREA COVERAGE RESULTS

Because cylinders (vertical samplers) of different diameters and therefore different cross-sectional areas have different

collection efficiencies, it is not permissible to present contamination densities on these cylindrical samplers in terms of any area other than the cross-sectional area of the sampler itself. It may be assumed, however, that a certain amount of agent collected by a vertical sampler corresponds to an amount of agent calculated for a square meter of horizontal contamination in proportion to the areas. For example, the cross-section of the vertical cylindrical sampler used on this series of trials has an area of 0.0065 square meter; thus, 0.65 milligrams collected on a vertical sampler corresponds to a horizontal contamination density of 100 milligrams per square meter. (For the collection of agent on bare skin areas, such as a wrist, the above assumption is essentially correct because the diameter of a wrist and of the vertical cylindrical sampler used are about the same. For the collection of agent over the entire body, the assumption results to some extent in an overestimation of the areas of effective vertical contamination). The area coverages, in square meters, obtained in these trials from the horizontal samplers and the vertical samplers are presented in Table 7.

TABLE 7: Area Coverage for Specified Contamination Density Levels Obtained on Indicated CW 442 Trials

CONTAMINATION DENSITY LEVELS		AREA OF CONTAMINATION (Square Meters) FOR INDICATED TRIALS					
		CW 442 A-1 Product: 1667; Rec*: 86%; Release Height: 165 ft; MW** - 10.1 mph		CW 442 A-2 Product: 3686; Rec: 79%; Release Height: 195 ft; MW - 18.9 mph		CW 442 A-3 Product: 2668; Rec: 73%; Release Height: 230 ft; MW - 11.6 mph	
Hori-zontal (mg/m^2)	Correspond-ing Vertical (mg/sampler)	horizontal	vertical	horizontal	vertical	horizontal	vertical
≥5	≥.0325	1,663,839	3,517,194	>3,275,232	>5,439,667	1,647,674	992,172
≥10	≥.065	1,314,349	2,801,493	2,514,431	>5,018,273	1,173,327	855,609
≥50	≥.325	707,898	1,189,492	1,045,125	2,580,763	554,613	445,920
≥100	≥.65	409,689	833,313	540,678	1,812,108	390,180	342,301
≥200	≥1.30	256,404	551,826	275,913	1,248,019	214,599	225,747
≥500	≥3.25	119,841	326,079	55,740	510,021	108,693	58,527
≥1,000	≥6.5	75,249	192,303	11,148	236,895	58,527	5,574
≥5,000	≥32.5	-	27,870	-	16,722	-	-
≥10,000	≥65.0	-	-	-	-	-	-

*Abbreviation for Recovery.
**Calculated Mean Wind.

Continued

TABLE 7: (Concluded)

CONTAMINATION DENSITY LEVELS		AREA OF CONTAMINATION (Square Meters) FOR INDICATED TRIALS							
		CW 442 B-1 Product: 3390; Rec: 75%; Release Height: 300 ft; MW - 11.3 mph		CW 442 B-2 Product: 3384; Rec: 66%; Release Height: 240 ft; MW - 14.1 mph		CW 442 B-3 Product: 4997; Rec: 77%; Release Height: 230 ft; MW - 21.7 mph		CW 442 B-4 Product: 1053; Rec: 79%; Release Height: 65 ft; MW - 16.2 mph	
Hori-zontal (mg/m^2)	Correspond-ing Vertical (mg/sampler)	horizontal	vertical	horizontal	vertical	horizontal	vertical	horizontal	vertical
≥5	≥.0325	>2,444,757	>3,593,000	2,352,785	>2,715,652	>3,203,935	>5,305,333	1,301,529	>4,338,802
≥10	≥.065	1,844,437	>2,749,096	1,864,503	2,361,146	>2,338,293	>5,231,199	969,876	>3,887,308
≥50	≥.325	685,602	1,047,912	758,064	1,098,078	863,970	>2,734,047	465,429	1,629,280
≥100	≥.65	401,328	643,797	504,447	699,537	546,252	1,974,868	342,801	1,106,439
≥200	≥1.30	245,256	334,440	197,877	351,162	287,061	1,237,428	236,895	724,620
≥500	≥3.25	86,397	158,859	91,971	111,480	69,675	632,649	114,267	445,920
≥1,000	≥6.5	27,870	69,675	11,148	36,231	5,574	239,682	39,018	259,191
≥5,000	≥32.5	2,787	-	-	-	-	-	2,787	52,953
≥10,000	≥65.0	-	-	-	-	-	-	-	8,361

DISCUSSION

The evaluation of this series of trials involved the estimation of mass-drop diameter spectra for each trial. Involved in these estimates is the assumption that at each downwind distance, only one drop diameter exists. As the result of this assumption, portions of the material of the drop diameter range containing the greater mass which fall out at greater and lesser downwind distances are attributed to the larger and smaller drop diameter ranges. Therefore, in Figures 4 A-G, the peaks of the curves are suppressed in varying degrees in each trial. This effect is especially noticeable in the comparison of Trial A-1 (low release height-wind speed product) with Trial B-3 (high product). Because of this, the spectra are presented as "apparent" mass-drop diameter spectra.

From the average of the cumulative spectra for the trials with the unmodified spray tank opening (Phase B), predictions have been made for area coverages at contamination density levels of $\geqslant$50, $\geqslant$100, $\geqslant$200, $\geqslant$500, and $\geqslant$1000 mg/m^2 for release height-wind speed products of 1,000 to 10,000 feet-miles/hour. These predictions, summarized in Figure 5, are for 90° (or 270°) $\pm$10° angle of aircraft heading with wind direction, an airspeed of 450 to 500 mph, maximum rate of flow of simulant from the spray tank, and the dissemination of 290 kg of simulant. Area coverages from the seven trials are also presented on this graph for the purpose of indicating the extent of variation, around the predicted area coverages, that may be expected in actual tests or operational use of the spray tank. These predictions and the above indications of expected variation are considered to be adequate for the described conditions of use, and further testing under these conditions would probably be of little value. An exception would be testing with the agent for establishing the relationship of simulant and agent mass-drop diameter spectra.

Predictions have also been prepared and presented (Fig. 6) for the area coverage-release height-wind speed product relationship for angles of aircraft heading with wind direction of less than 90° (or 270°). Because of the assumptions involved in these predictions, they are considered to be less and less reliable as an angle approaches 0° (or 180°). It is probable that the extent of this unreliability cannot be determined without further testing at an angle of or close to 0° or 180°.

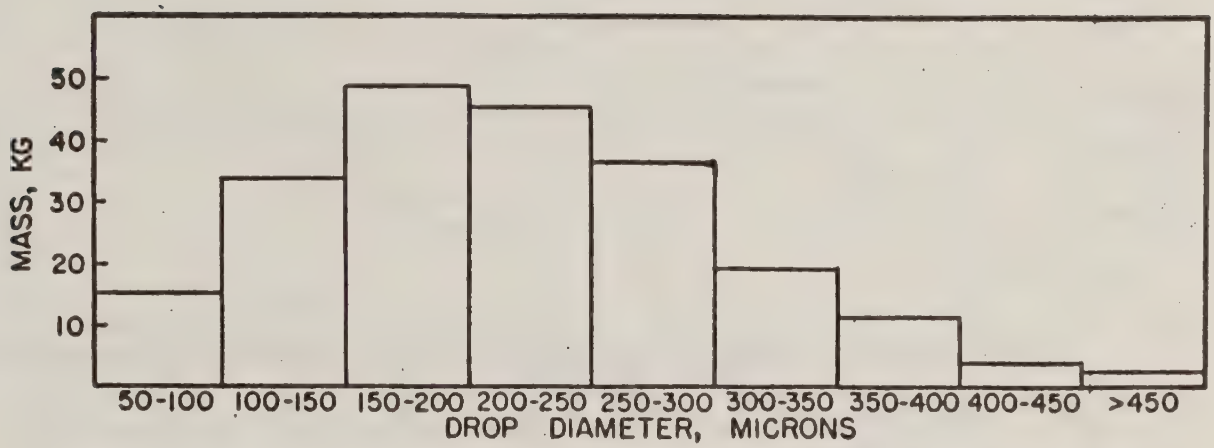

Fig. 4A.- Apparent Mass-Drop Diameter Spectra for Trial CW 442 A-1.

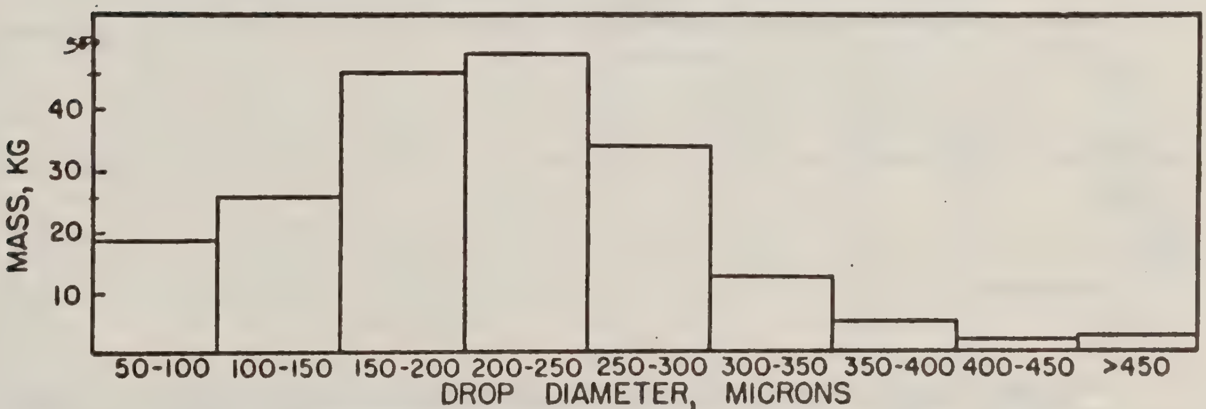

Fig. 4B.- Apparent Mass-Drop Diameter Spectra for Trial CW 442 A-2.

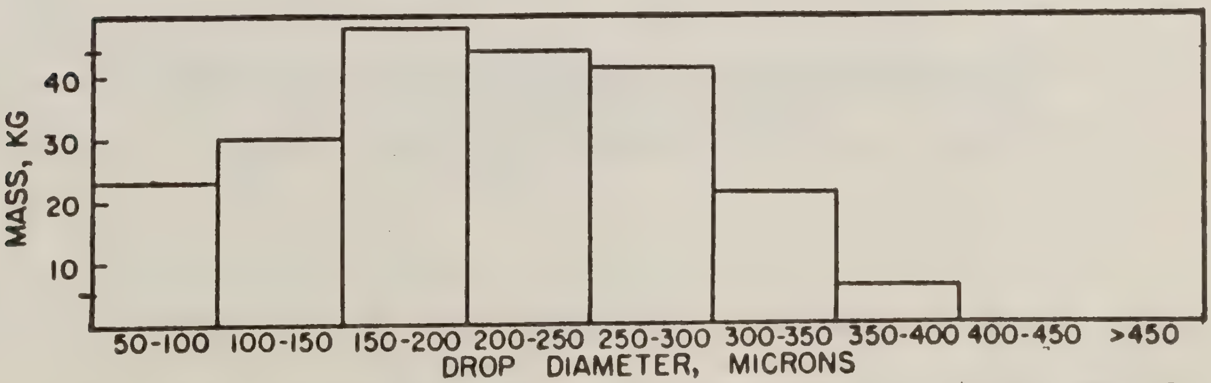

Fig. 4C.- Apparent Mass-Drop Diameter Spectra for Trial CW 442 A-3.

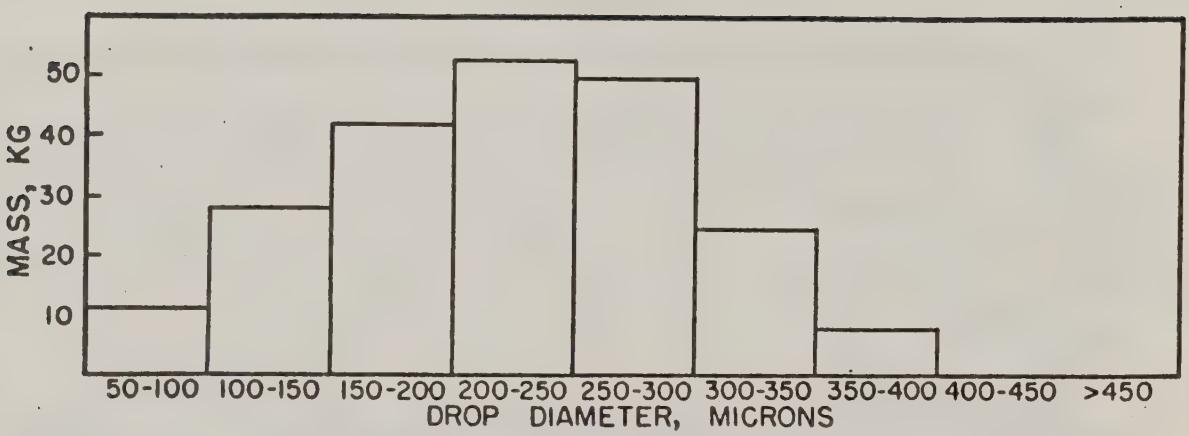

Fig. 4D.- Apparent Mass-Drop Diameter Spectra for Trial CW 442 B-1.

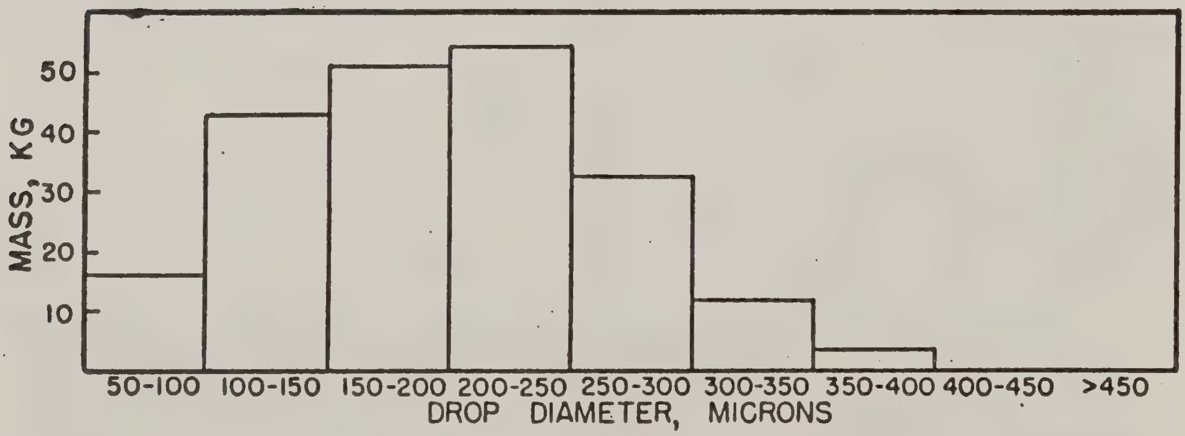

Fig. 4E.- Apparent Mass-Drop Diameter Spectra for Trial CW 442 B-2.

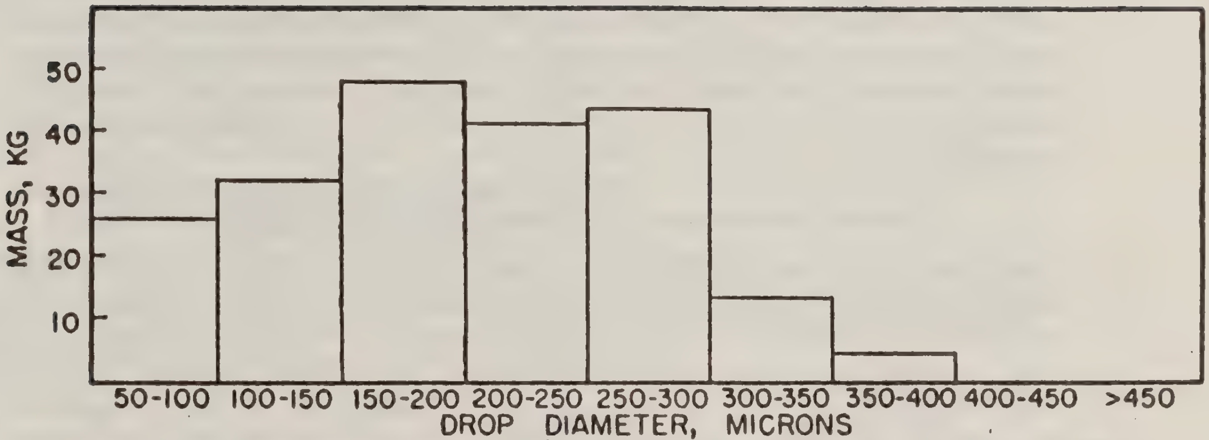

Fig. 4F.- Apparent Mass-Drop Diameter Spectra for Trial CW 442
B-3.

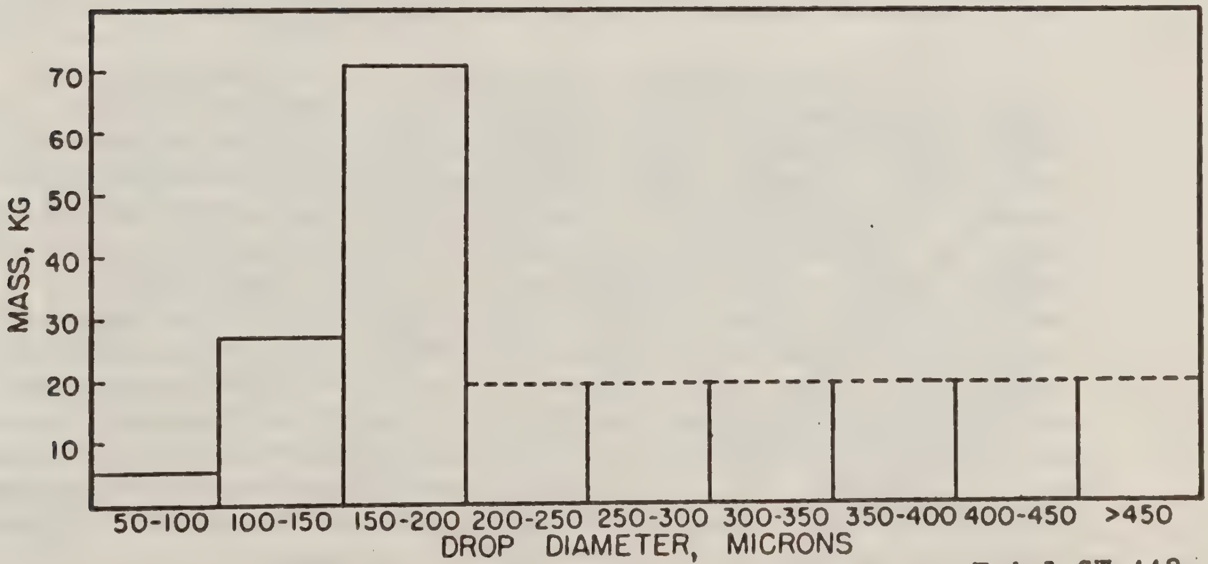

Fig. 4G.- Apparent Mass-Drop Diameter Spectra for Trial CW 442
B-4.

III. Predictions of Area Coverage (Angles of less than 90° or 180° between Aircraft Heading and Wind Direction).

A. For these predictions, the same hypothetical grid was used with the line of flight parallel to the grid rows. A decrease from 90° of the angle of wind direction with the aircraft heading will thus produce an increase in downwind distance between the rows having a constant down-grid distance difference of 300 feet (see Fig. 15). Thus, according to the equation,

$$\text{Rate of Fall} = \frac{\text{Release Height-Wind Speed Product,}}{\text{Downwind Distance}}$$

a decrease in the angle would result in an increase in the downwind distance and a corresponding increase in the release height-wind speed product if the rate of fall for the drop landing at this distance is to remain constant. Thus the kg/row of the 90° predictions and the corresponding increments of drop diameter and rates of fall, if held constant, call for an increase in release height-wind speed products for each increase in downwind distance between grid rows resulting from each decrease in angle. The predictions for area coverages at the smaller angles, Figure 16, therefore consists of the same curves as in Figure 14 with a new release height-wind speed product scale superimposed for each angle between aircraft heading and wind direction.

B. In the above predictions for the smaller angles, lateral or cross wind diffusion has been neglected for the most part. For an angle of 0°, this assumption implies the unlikely result that a nearly zero area of nearly infinite contamination density will be obtained. The assumption has also been made that the relationships of Figure 13 are valid for all of the smaller angles. The validity of this latter assumption is doubtful. For these reasons, the predictions become less reliable as the angle becomes smaller. One or more trials at an angle of or close to 0° would be required to give an estimate of lateral diffusion and to provide a check on the usefulness and validity of Figure 13 for the small angle predictions. It should be noted that, in Figure 13, a certain amount of lateral diffusion effect is apparent in the downward slope of the 100 mg/m^2 line on the right hand side of the graph.

IV. Reliability of the Predictions.

A. The predictions given above are based on the average apparent mass-drop diameter spectrum of the trials of Phase B.

On a theoretical basis, it is expected that the apparent spectra should be more "peaked" at low release height-wind speed product and more "flattened" at high products. All attempts to derive a quantitative relationship from the available data were unsuccessful. The predictions therefore suffer from the use of an average spectrum and from the fact that this average is for a lower average release height-wind speed product than the indicated range of "products" required for the best area coverage.

B. A closely related problem involves the assumption used in the prediction that each downwind distance involves only one drop diameter. The actual spread of the drops of one diameter is over a considerable downwind distance (see Fig. 1). Although this separation in downwind distance of drops of the same diameter is very small in comparison to the separation of drops of different diameters, the above assumption has a slight effect on the reliability of the prediction.

C. In Figure 13, the spread of points around the curves is attributed to the assumption that the mass of simulant assigned to each row is the only variable of importance and to the chance occurrence and distribution of contamination densities having values just above or below the selected level of interest. No obvious relationship of any other variable with the number of sampling positions (at a certain level of contamination density) could be found.

D. In addition to the above, other small errors in the predictions may have resulted from the use of the graphic rather than the mathematical methods and from the use of other simplifying assumptions. The predictions for area coverage (for an angle of aircraft heading with wind direction of close to 90° or 270°, air speed of 450 to 500 mph, maximum rate of flow, and dissemination of 290 kg of simulant), in spite of the possible errors outlined above, are considered to be entirely adequate for operational planning and use of the spray tank. This statement is based on the apparent insignificance of the prediction error in comparison to the probable error in operational estimation of wind speed on one hand and, on the other hand, the large spread in release height-wind speed products in which the near-maximum area coverage can be obtained.

V. Summary

A. Near-maximum area coverages may be achieved at a large spread of release height-wind speed products. For the use of the simulant, with dissemination at full flow rate, released at a 90° or 270° angle with the wind direction, and the substantially complete release of the tank's contents, adequate predictions of area coverage have been obtained for most conditions likely to be encountered in operational use. It is likely that this same near-maximum area coverage may also be obtained from the dissemination of the contents of one spray tank of the toxic agent at any air speed, any angle of aircraft heading and wind direction, and any rate of flow of agent from the tank. It is also likely that this area coverage can be accomplished over a large range of release height-wind speed products. Useful and reliable predictions for these ranges of products remain to be established for small angles of aircraft heading with wind direction, for decreased rates of flow, for air speeds above 500 mph or below 450 mph, and for trials with the use of agent in place of simulant.

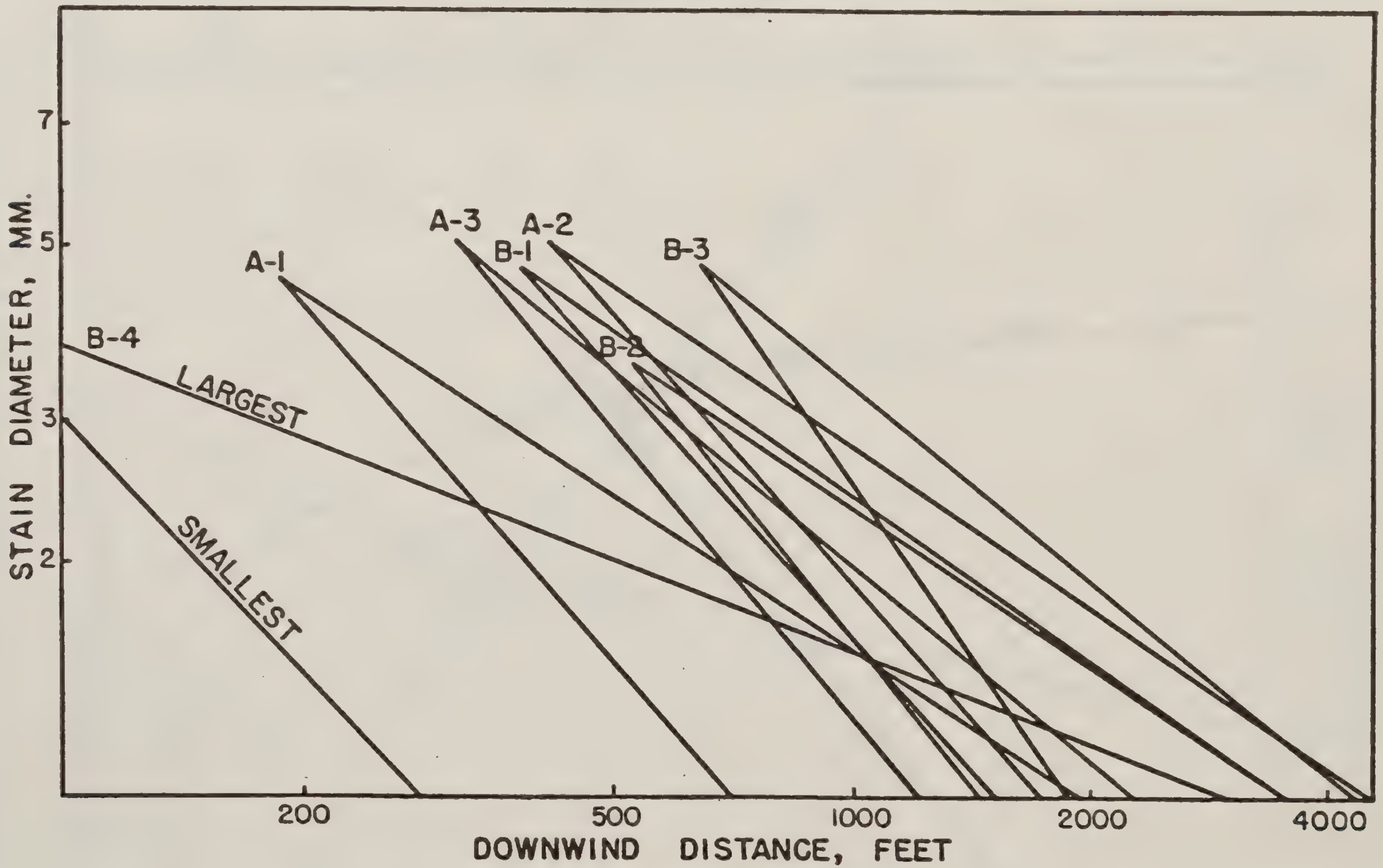

Fig. 1.- Stain Diameter versus Downwind Distance for CW 442 Series.

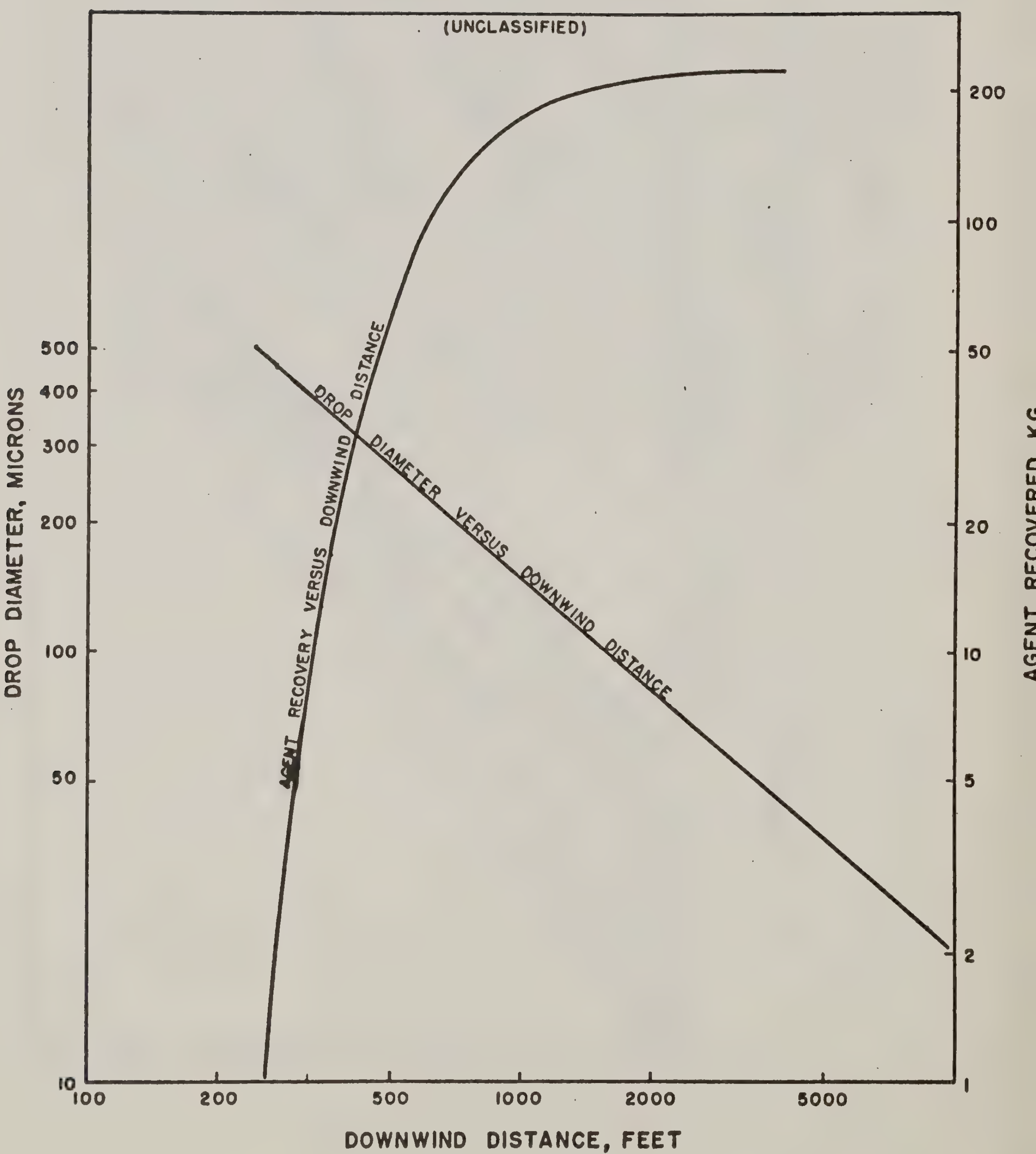

Fig. 2.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 A-1.

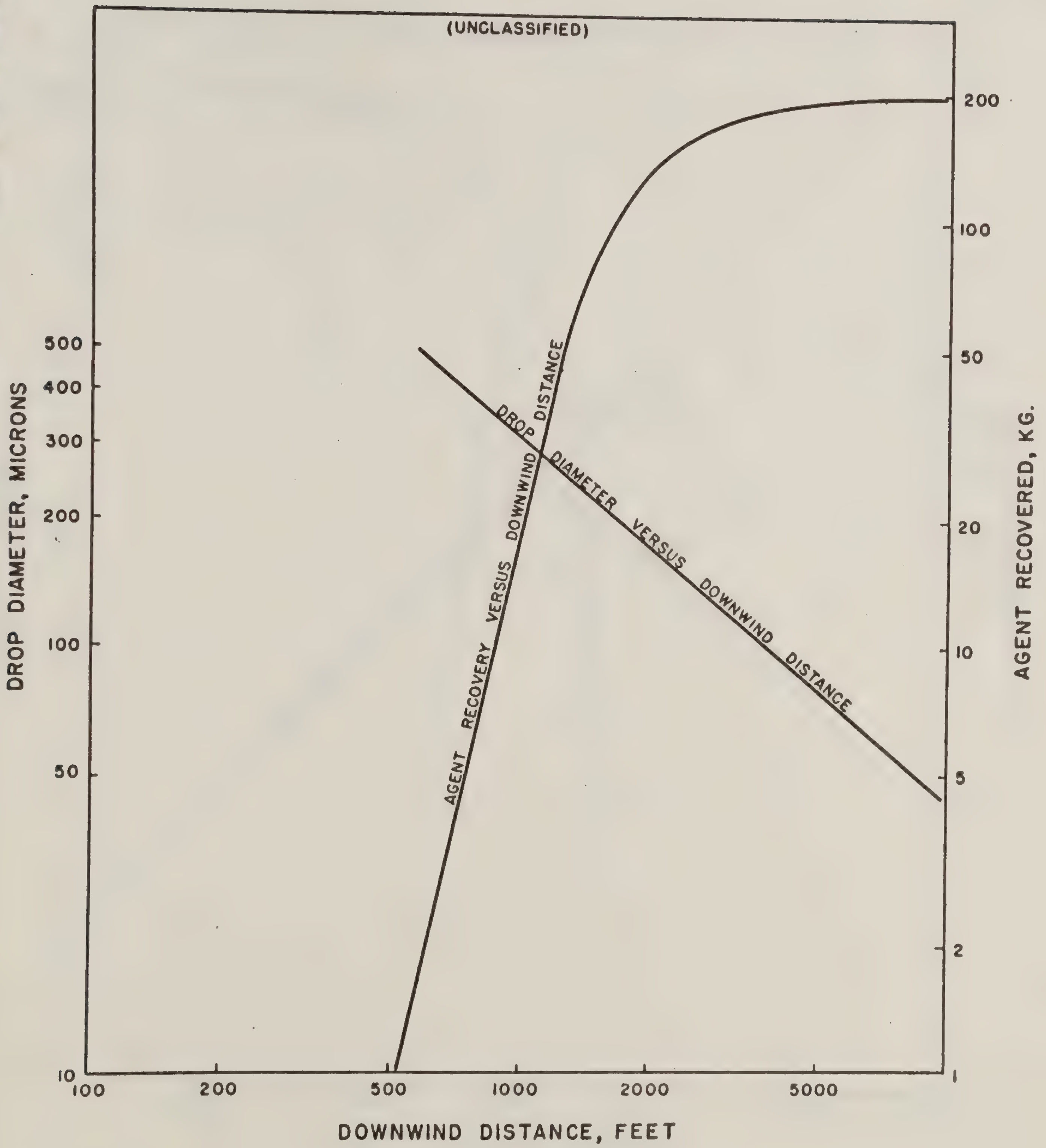

Fig. 3.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 A-2.

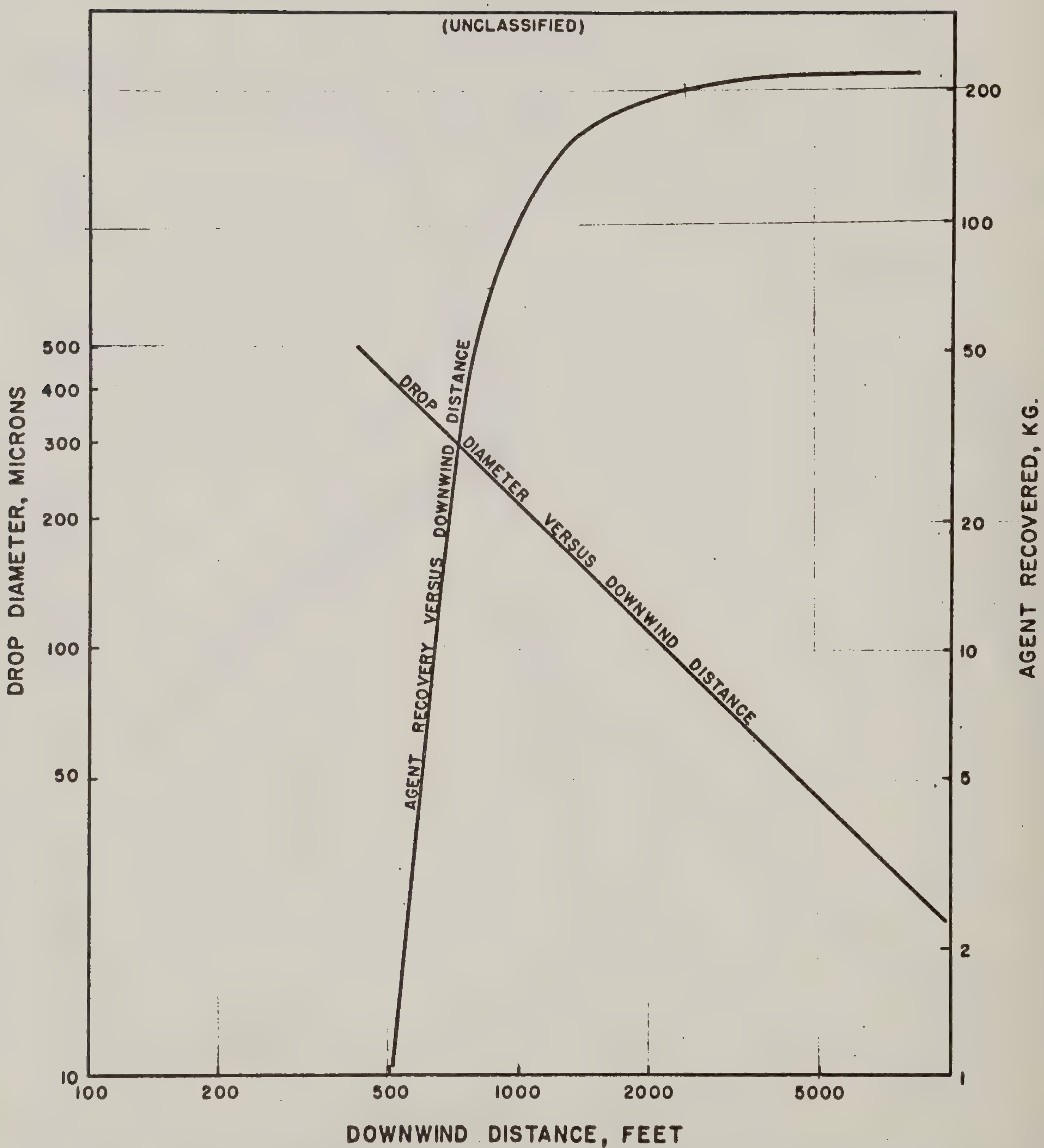

Fig. 4.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 A-3.

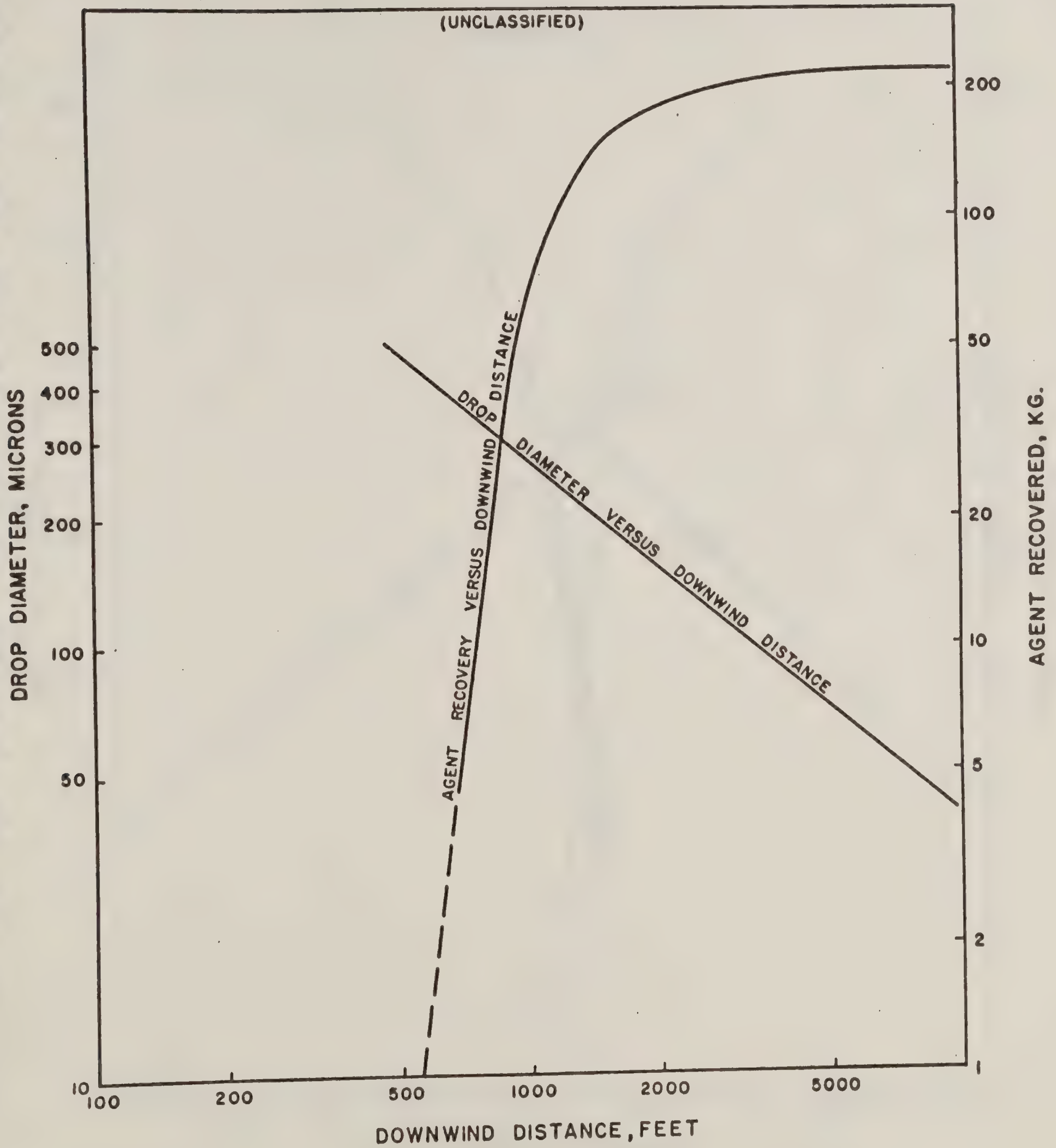

Fig. 5.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 B-1.

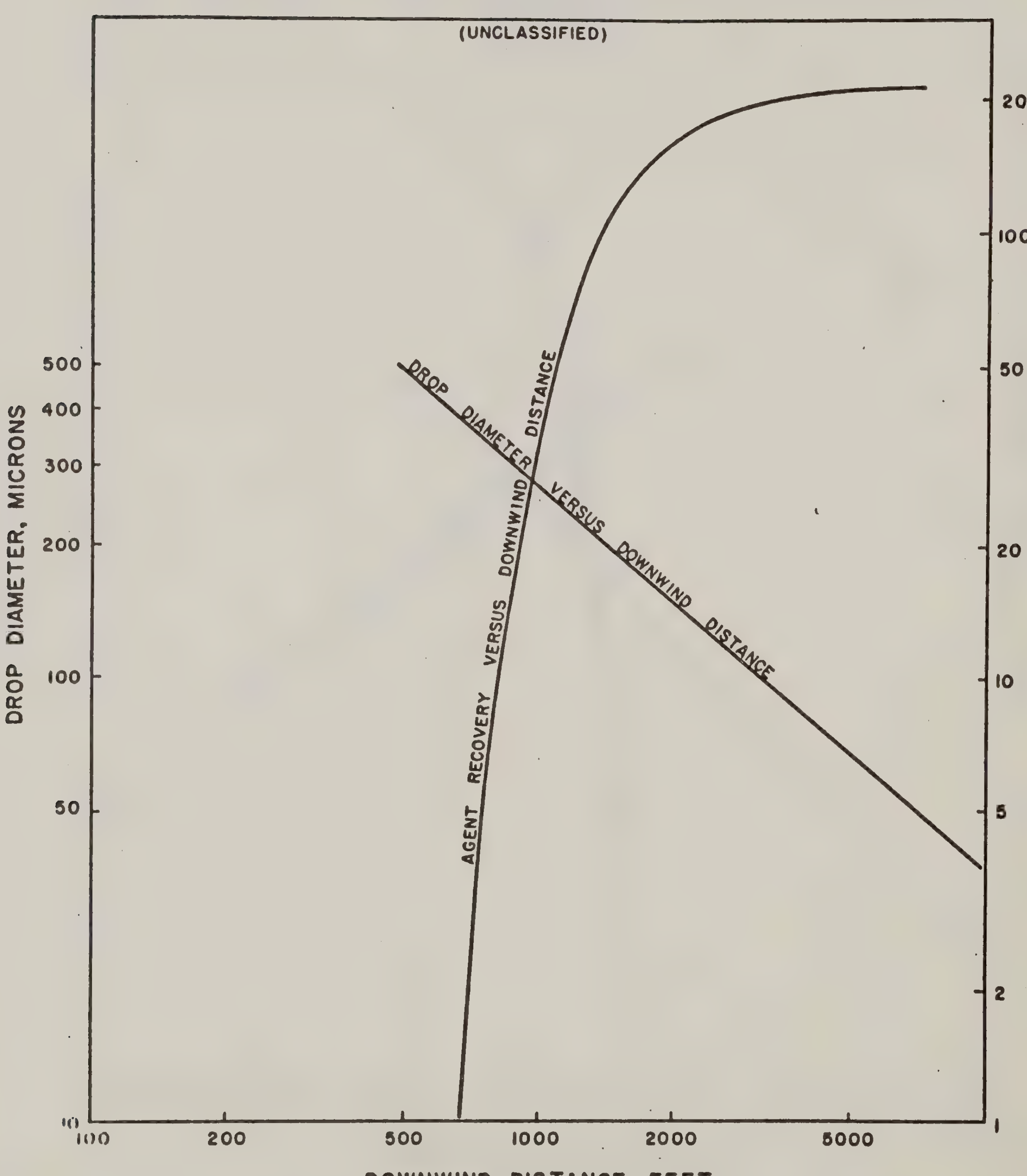

Fig. 6.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 B-2.

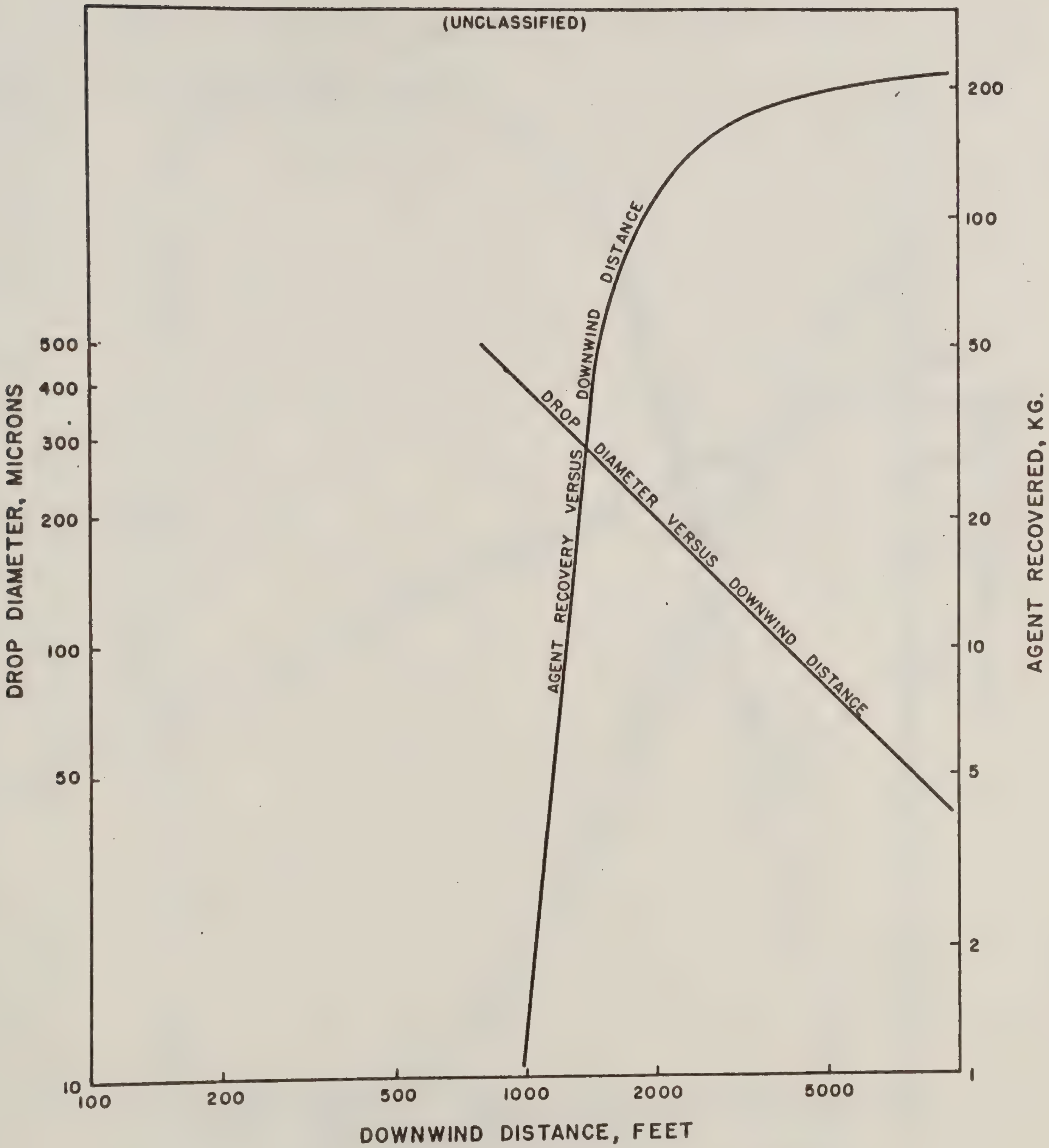

Fig. 7.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 B-3.

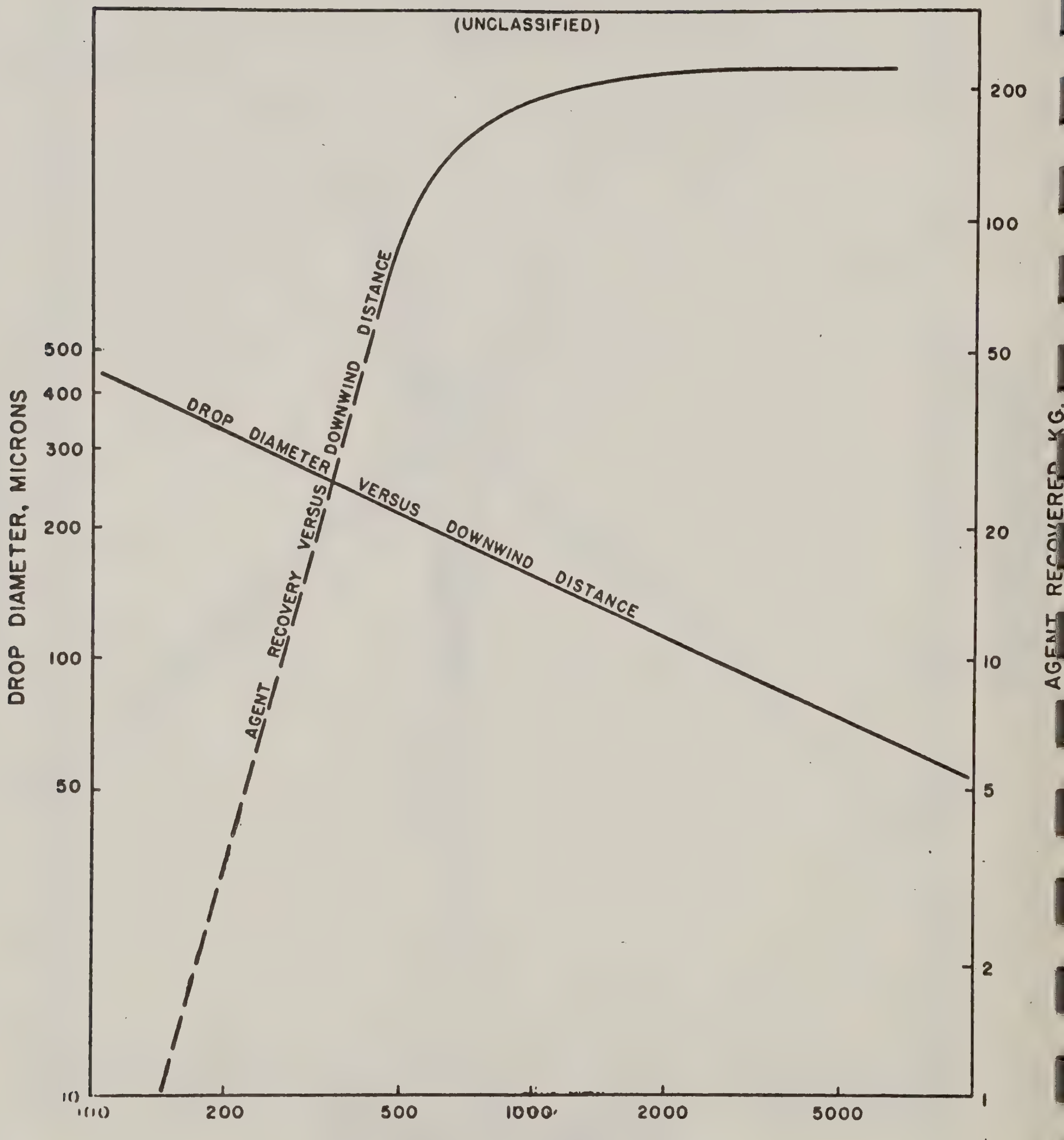

Fig. 8.- Agent Recovery and Drop Diameter versus Downwind Distance for CW 442 B-4.

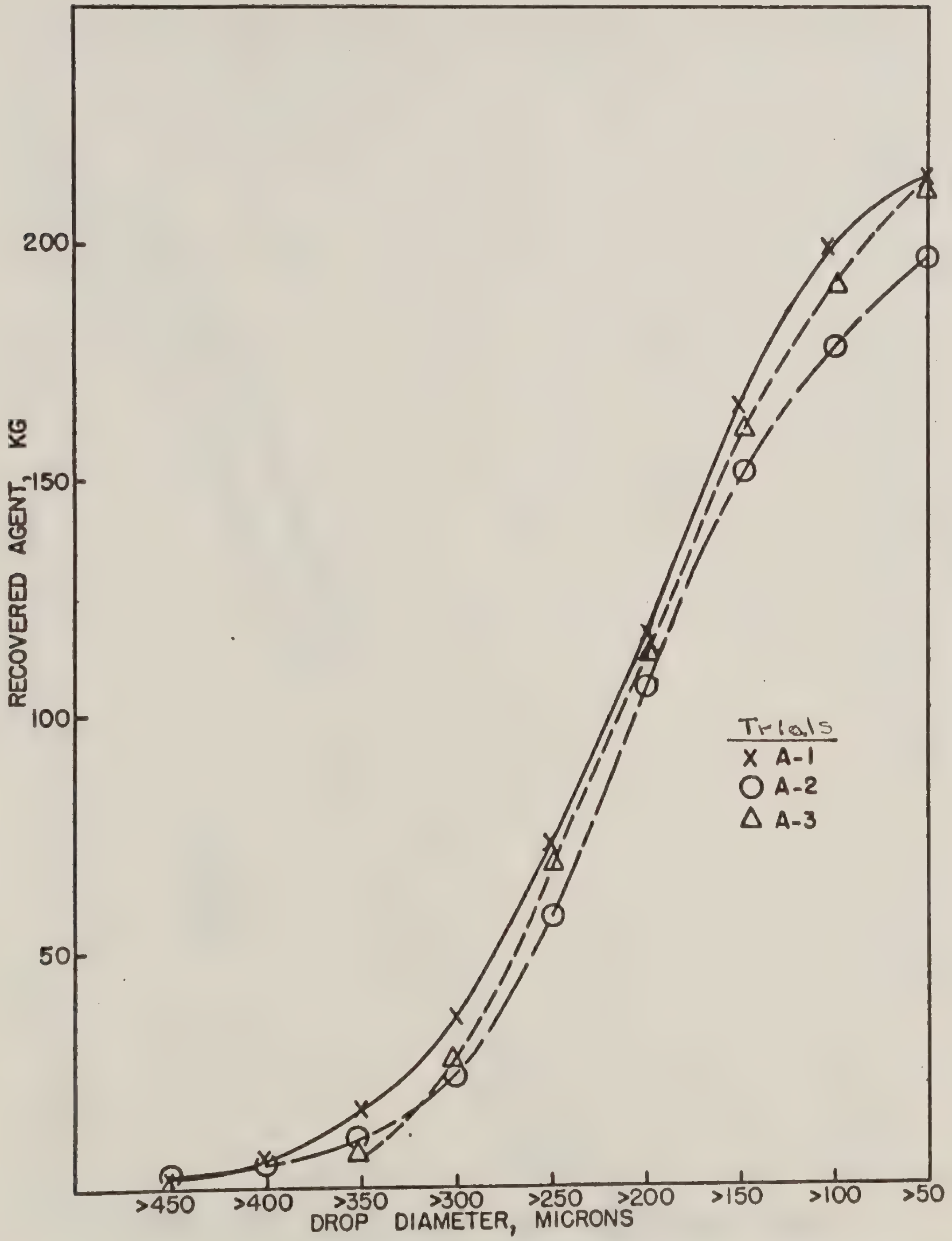

Fig. 9.- Cumulative Mass-Drop Diameter Spectra (Apparent) for CW 442, Phase A.

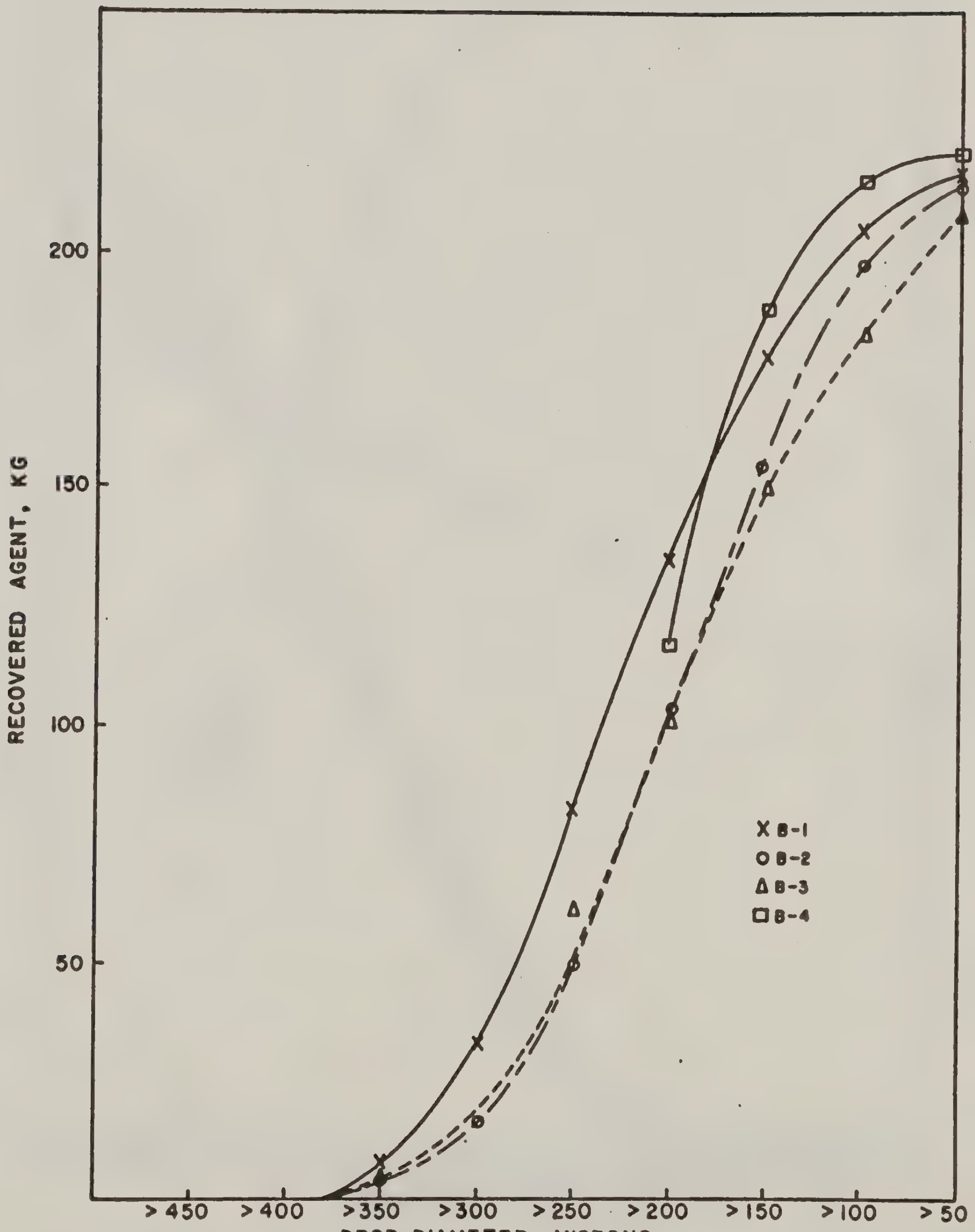

Fig. 10.- Cumulative Mass-Drop Diameter Spectra (Apparent) for CW 442, Phase B.

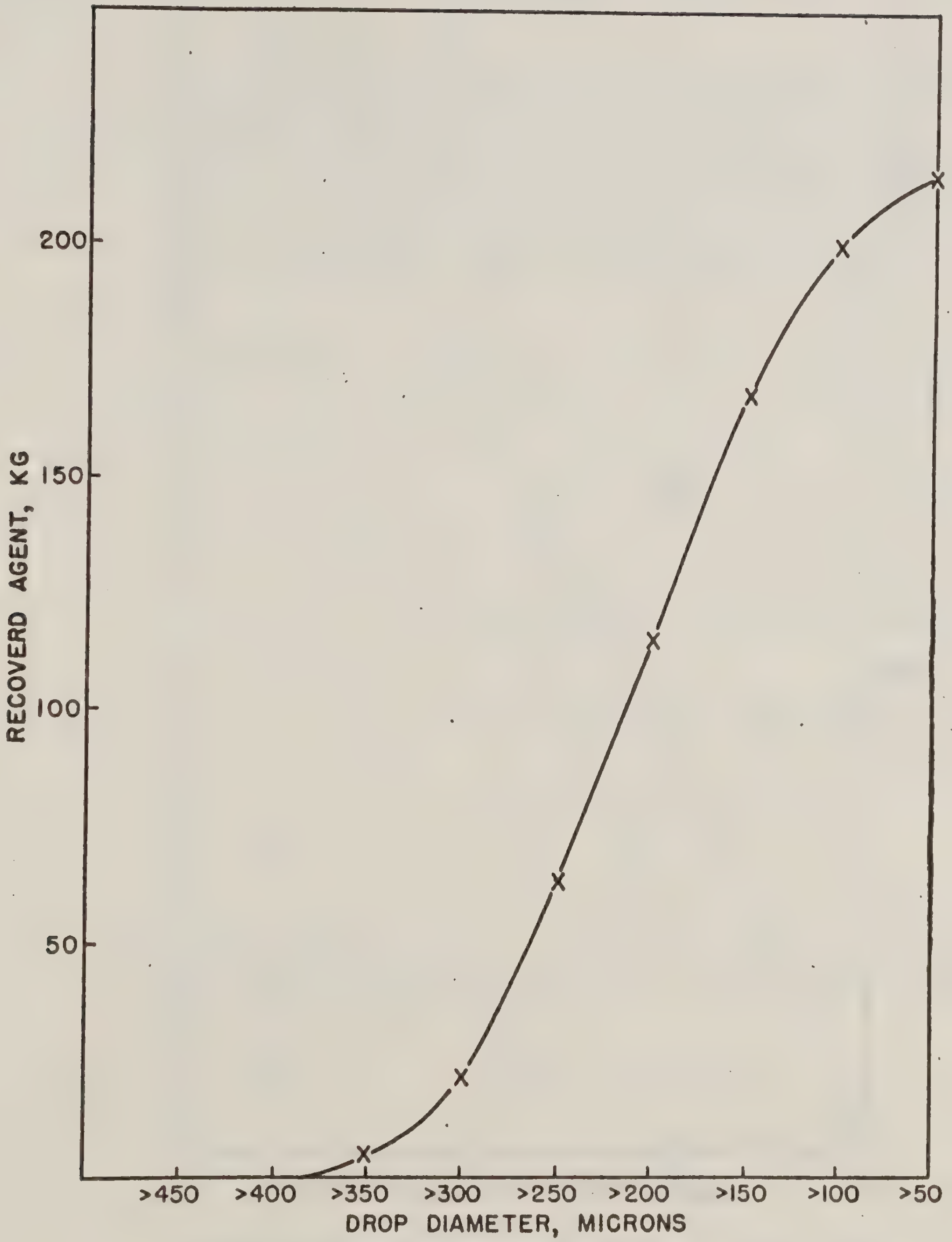

Fig. 11.- Average Cumulative Mass-Drop Diameter Spectra (Apparent) for CW 442, Phase B.

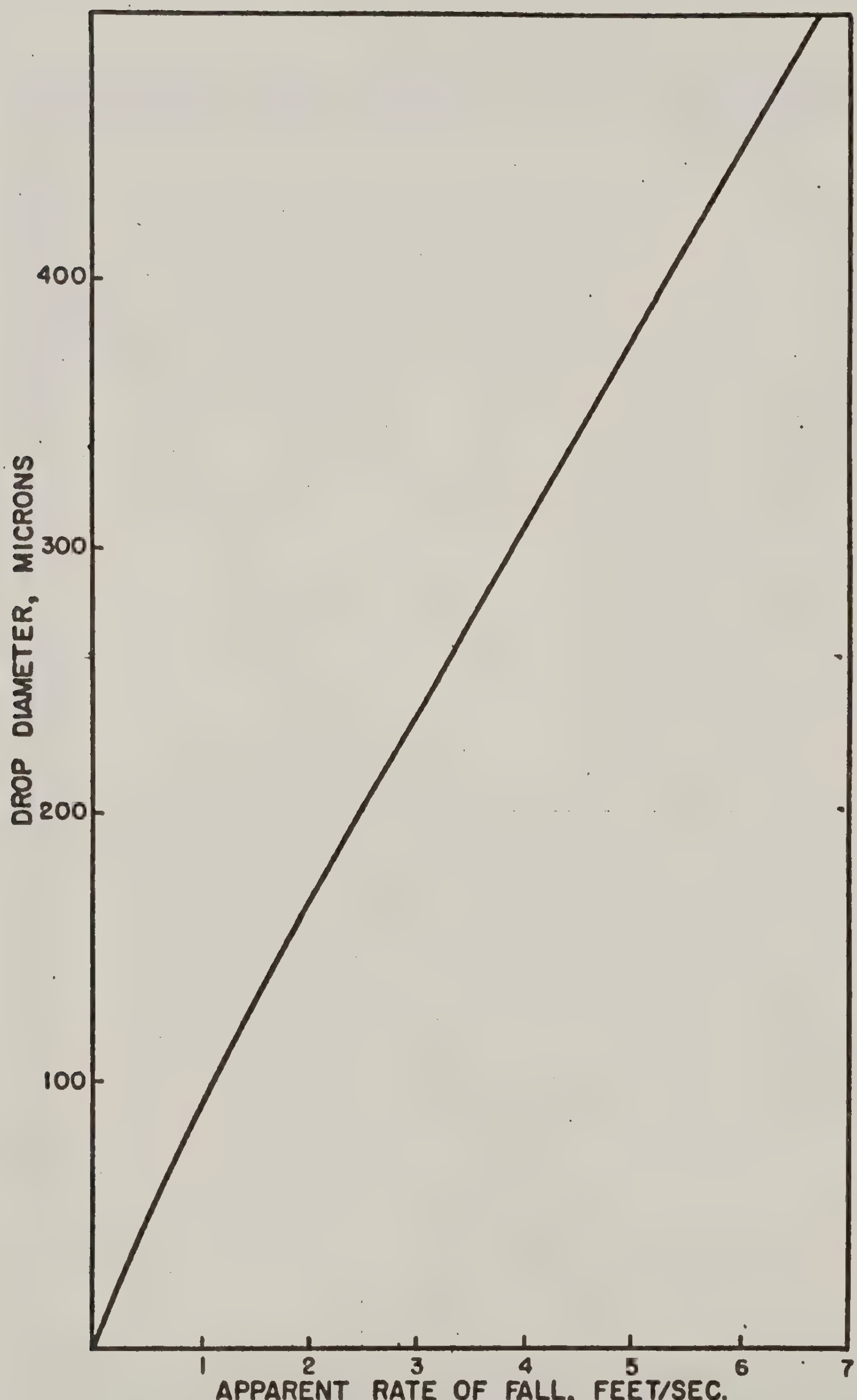

Fig. 12.- Drop Diameter versus Apparent Rate of Fall for CW 442 Series.

TAB 2

CALCULATION OF SPREAD FACTOR

Advantage was taken of "paired sampling" on these trials to determine a spread factor based on conditions actually occuring during the spread of the dyed simulant in the field. The assumption has been made that the volume of simulant collected on the filter paper is equivalent to the volume collected on that portion of the Printflex card having the same area as the exposed portion of the filter paper. The volume collected on the filter paper was measured as mass and converted by assuming a density of 1.

Therefore, for the J_{th} set of paired sampling cards

1. $$Va = Vc = \sum_{i=1}^{n} \frac{\pi}{6} D_{ci}^{3}$$

where V = simulant recovery by volume

a = by chemical extraction analysis (filter card)

c = by arithmetical computation based on drop stain diameter (Printflex card)

D = drop stain diameter

2. $$\frac{6}{\pi} Va = \sum_{i=1}^{n} D_{ci}^{3}$$

Since the equality of No. 2 is not encountered, it becomes necessary to introduce a weight "k" or "Spread Factor" which will create this balance. Hence,

3. $$\frac{6}{\pi} Va = k^{3} \sum_{i=1}^{n} D_{ci}^{3}$$

4. $$k = \sqrt[3]{\frac{6}{\pi} Va + \sum_{i=1}^{n} D_{ci}^{3}}$$

Evaluating a weighted average k or Spread Factor

$$5. \qquad k_w = \sum_{j=1}^{n} k\,Va \div \sum_{j=1}^{n} Va$$

The derived "k" or "Spread Factor" for each set of sampling cards of the trial B-3 is listed under Column VII, Table 5. The factor is based on data from this test only. Substituting appropriate values into equation No. 5 above

$$k_w = 4.0849 \div 30.900$$

$$= 0.1322$$

Thus, if the ratio of the estimate by chemical analysis to the estimate by arithmetical computation is k_w, indicated above, the estimate by arithmetical computation to the estimate by chemical analysis is the inverse of k_w or 7.57.

TABLE 1A: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)					
		390-347		390-355		390-403	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
1.6	4.096			1	4.096		
1.7	4.913						
1.8	5.832						
1.9	6.859						
2.0	8.000						
2.1	9.261			2	18.522	2	18.522
2.2	10.648			1	10.648	1	10.648
2.3	12.167			1	12.167		
2.4	13.824	1	13.824	2	27.648		
2.5	15.625						
2.6	17.576	3	52.728	1	17.576	1	17.576
2.7	19.683	4	78.732			3	59.049
2.8	21.952	7	153.664	2	43.904	2	43.904
2.9	24.389	6	146.334	2	48.778	9	219.501
3.0	27.000	8	216.000	7	189.000	17	459.000
3.1	29.791	3	89.373	2	59.582	13	387.283
3.2	32.768	7	229.376	10	327.680	8	262.144
3.3	35.937	2	71.874	4	143.748	5	179.685
3.4	39.304	3	117.912	5	196.520	3	117.912
3.5	42.875			1	42.875	1	42.875
3.6	46.656					1	46.656
3.7	50.653					1	50.653
3.8	54.872			1	54.872		
3.9	59.319						
4.0	64.000						
4.1	68.921	1	68.921				
4.2	74.088						
4.3	79.507						
4.4	85.184						
4.5	91.125						
4.6	97.336						
4.7	103.823						
4.8	110.592						
Sum	Σ		1238.738		1197.616		1915.408

TABLE 1B: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)					
		390-507		390-539		390-555	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
1.6	4.096						
1.7	4.913					1	4.913
1.8	5.832					1	5.832
1.9	6.859						
2.0	8.000						
2.1	9.261						
2.2	10.648						
2.3	12.167						
2.4	13.824	1	13.824			1	13.824
2.5	15.625					1	15.625
2.6	17.576			1	17.576	2	35.152
2.7	19.683	2	39.366	5	94.415	1	19.683
2.8	21.952	2	43.904	4	87.808	11	241.472
2.9	24.389	3	73.167	4	97.556	7	170.723
3.0	27.000	8	216.000	5	135.000	6	162.000
3.1	29.791	14	417.074	3	89.373	9	268.119
3.2	32.768	21	688.128	4	131.072	10	327.680
3.3	35.937	6	215.622	2	71.874		
3.4	39.304	6	235.824	2	78.608	2	78.608
3.5	42.875	12	514.500	1	42.875	1	42.875
3.6	46.656	4	186.624				
3.7	50.653						
3.8	54.872	2	109.744				
3.9	59.319	1	59.319				
4.0	64.000					1	64.000
4.1	68.921						
4.2	74.088						
4.3	79.507						
4.4	85.184						
4.5	91.125	1	91.125				
4.6	97.336						
4.7	103.823						
4.8	110.592	1	110.592				
Sum	Σ		3014.813		850.157		1450.506

TABLE 2A: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)									
		414-403		414-547		414-555		414-563		414-571	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
1.3	2.197									1	2.197
1.4	2.744									1	2.744
1.5	3.375										
1.6	4.096					1	4.096				
1.7	4.913										
1.8	5.832			6	34.992	4	23.328	2	11.664		
1.9	6.859			10	68.590	13	89.167	3	20.577		
2.0	8.000	2	16.000	11	88.000	11	88.000			1	8.000
2.1	9.261	2	18.522	18	166.698	11	101.871	8	74.088	1	9.261
2.2	10.648	1	10.648	27	287.496	9	95.832	10	106.480	8	85.184
2.3	12.167	2	24.334	12	146.004	5	60.835	6	73.002	4	48.668
2.4	13.824	7	124.416	12	165.888	6	82.944	4	55.296	12	165.888
2.5	15.625	5	78.125	13	203.125			6	93.750	9	140.625
2.6	17.576	16	281.216	15	263.640	1	17.576	4	70.304	5	87.880
2.7	19.683	12	236.196	9	177.147			5	98.415		
2.8	21.952	19	417.088	3	65.856	2	43.904	3	65.856	4	87.808
2.9	24.389	8	195.112	2	48.778	1	24.389	3	73.167	3	73.167
3.0	27.000	9	243.000	1	27.000	2	54.000			3	81.000
3.1	29.791	4	119.164			1	29.791	1	29.791	1	29.791
3.2	32.768			1	32.768			2	65.536	1	32.768
3.3	35.937										
3.4	39.304									1	39.304
3.5	42.875									1	42.875
3.6	46.656									1	46.565
Sum	Σ		1763.821		1775.982		715.733		837.926		983.816

TABLE 2B: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)							
		414-579		414-636		414-651		414-659	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
1.3	2.197								
1.4	2.744					2	5.488		
1.5	3.375								
1.6	4.096			1	4.096				
1.7	4.913								
1.8	5.832							2	11.664
1.9	6.859							4	27.436
2.0	8.000			2	16.000	1	8.000	12	96.000
2.1	9.261							14	129.654
2.2	10.648					2	21.296	15	159.720
2.3	12.167	3	36.501			4	48.668	10	121.670
2.4	13.824	3	41.472			15	207.360	9	124.416
2.5	15.625	2	31.250			10	156.250	2	31.250
2.6	17.576	7	123.032			2	35.152	1	17.576
2.7	19.683	7	137.781						
2.8	21.952	10	219.520	1	21.592	4	87.808		
2.9	24.389	4	97.556	3	73.167	4	97.556	2	48.778
3.0	27.000	3	81.000	4	108.000	3	81.000	1	27.000
3.1	29.791	1	29.791	1	29.791				
3.2	32.768	2	65.536	3	98.304	1	32.768		
3.3	35.937			1	35.937				
3.4	39.304			1	39.304				
3.5	42.875								
3.6	46.656								
Sum	Σ		863.439		426.551		781.346		795.164

TABLE 3A: Stain Size Data for CW 443 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)									
		438-555		438-571		438-579		438-595		438-603	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
0.9	0.729	2	1.458								
1.0	1.000	6	6.000								
1.1	1.331	4	5.324								
1.2	1.728	14	24.192							2	3.456
1.3	2.197	26	57.122	2	4.394			7	15.379		
1.4	2.744	32	87.808	6	16.464			17	46.648		
1.5	3.375	20	67.500	5	16.875			23	77.625	2	6.750
1.6	4.096	12	49.152	4	16.384			16	65.536	4	16.384
1.7	4.913	26	127.738	1	4.913			21	103.173	20	98.260
1.8	5.832	14	81.648	4	23.328	4	23.328	13	75.816	50	291.600
1.9	6.859	14	96.026	4	27.436	16	109.744	12	82.308	40	274.360
2.0	8.000	2	16.000	4	32.000	18	144.000	8	64.000	52	416.000
2.1	9.261	6	55.566	5	46.305	30	277.830	9	83.349	36	333.396
2.2	10.648	12	127.766	12	127.766	8	85.184	9	95.832	12	127.776
2.3	12.167			10	121.670	16	194.672	8	97.336	4	48.668
2.4	13.824	2	27.648	17	235.008	2	27.648	2	27.648	4	55.296
2.5	15.625	2	31.250	8	125.000			2	31.250	2	31.250
2.6	17.576	2	35.152	4	70.304			1	17.576		
2.7	19.683			2	39.366						
2.8	21.952			1	21.952						
2.9	24.389	2	48.778								
3.0	27.000										
3.1	29.791										
3.2	32.768										
Sum	Σ		946.138		927.175		862.406		883.476		1703.196

TABLE 3B: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)							
		438-611		438-627		438-659		438-667	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
0.9	0.729								
1.0	1.000								
1.1	1.331								
1.2	1.728								
1.3	2.197	6	13.182						
1.4	2.744	23	63.112			2	5.488	28	76.832
1.5	3.375	8	27.000	1	3.375	5	16.875	32	108.000
1.6	4.096	2	8.192			1	4.096	32	131.072
1.7	4.913					5	24.565	36	176.868
1.8	5.832	8	46.656	3	17.496	6	34.992	24	139.968
1.9	6.859	11	75.449			6	41.154	20	137.180
2.0	8.000	14	112.000	3	24.000	24	192.000	30	240.000
2.1	9.261	14	129.654	13	120.393	15	138.915	34	314.874
2.2	10.648	13	138.424	20	212.960	26	276.848	34	362.032
2.3	12.167	11	133.837	15	182.505	15	182.505	6	73.002
2.4	13.824	4	55.296	9	124.416	7	96.768	6	82.944
2.5	15.625	3	46.875	8	125.000	11	171.875	10	156.250
2.6	17.576	4	70.304	7	123.032	4	70.304	2	35.152
2.7	19.683			1	19.683			2	39.366
2.8	21.952	1	21.952	3	65.856	1	21.952	2	43.904
2.9	24.389			4	97.556				
3.0	27.000	1	27.000	1	27.000	1	27.000	2	54.000
3.1	29.791								
3.2	32.768	1	32.768	2	65.536				
Sum	Σ		1001.701		1208.808		1305.337		2171.444

TABLE 4A: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)							
		486-283		486-563		486-571		486-259	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
0.1	.001								
0.2	.008	4	.032					26	.208
0.3	.027	8	.216					32	.864
0.4	.064	6	.384					26	1.664
0.5	.125	22	2.750			2	.250	48	6.000
0.6	.216	24	5.184					32	6.912
0.7	.343	36	12.348	2	.686			18	6.174
0.8	.512	30	15.360	4	2.048	6	3.072	20	10.240
0.9	.729	10	7.290	8	5.832	6	4.374	4	2.916
1.0	1.000	12	12.000	20	20.000	18	18.000	2	2.000
1.1	1.331	2	2.662	22	29.282	20	26.620		
1.2	1.728	4	6.912	30	51.840	40	69.120	2	3.456
1.3	2.197	2	4.394	14	30.758	42	92.274		
1.4	2.744			24	65.856	30	82.320		
1.5	3.375			22	74.250	24	81.000		
1.6	4.096			16	65.536	36	147.456		
1.7	4.193			10	49.130	10	49.130		
1.8	5.832			6	34.992	10	58.320		
1.9	6.859			2	13.718	8	54.872		
2.0	8.000			4	32.000	14	112.000		
2.1	9.261								
2.2	10.648					2	21.296		
2.3	12.167								
2.4	13.824					2	27.648		
Sum	Σ		69.532		475.928		847.752		40.434

TABLE 4B: Stain Size Data for CW 442 B-3

DROP STAIN DIAMETER		SAMPLING LOCATION (Row and Position)					
		582-267		582-659		654-275	
(mm)	$(mm)^3$	Number	ΣD^3	Number	ΣD^3	Number	ΣD^3
0.1	.001					16	.016
0.2	.008	4	.032	4	.032	68	.544
0.3	.027	16	.432	2	.054	76	2.052
0.4	.064	34	2.176	10	.640	76	4.864
0.5	.125	40	5.000	16	2.000	88	11.000
0.6	.216	34	7.344	14	3.024	60	12.960
0.7	.343	48	16.464	20	6.860	64	21.952
0.8	.512	38	19.456	16	8.192	52	26.624
0.9	.729	28	20.412	28	20.412	24	17.496
1.0	1.000	10	10.000	28	28.000	8	8.000
1.1	1.331			20	26.620	4	5.324
1.2	1.728	2	3.456	18	31.104	4	6.912
1.3	2.197			8	17.576		
1.4	2.744			2	5.488		
1.5	3.375						
1.6	4.096						
1.7	4.913						
1.8	5.832						
1.9	6.859						
2.0	8.000						
2.1	9.261						
2.2	10.648						
2.3	12.167						
2.4	13.824						
Sum	Σ		84.772		150.002		117.744

TABLE 5: Summary Sheet, Volumes, Diameters, and Spread Factors for CW 442 B-3

I	II	III	IV	V	VI	VII
LOCATION		FILTER PAPER SIMULANT VOLUME		PRINTFLEX	SPREAD FACTOR	
Row	Position	Va $(mm)^3$	$\frac{6}{\pi}$ Va	$\sum_{i=1}^{n} D_c^3$ $(mm)^3$	k^3 (IV ÷ V)	k $\sqrt[3]{VI}$
390-	347	0.700	1.3369	1,238.738	0.001079	0.10257
	355	1.430	2.7311	1,197.616	.002280	.13162
	403	0.360	0.6875	1,915.408	.000359	.07107
	507	3.065	5.8537	3,014.813	.001942	.12476
	539	0.670	1.2796	850.157	.001505	.11460
	555	1.050	2.0054	1,450.506	.001383	.11140
414-	403	1.260	2.4064	1,763.821	.001364	.11091
	547	2.700	5.1566	1,775.982	.002904	.14266
	555	0.745	1.4228	715.733	.001987	.12574
	563	1.435	2.7406	837.926	.003271	.14844
	571	2.525	4.8224	983.816	.004902	.16987
	579	0.590	1.1268	863.439	.001305	.10928
	635	0.115	0.2196	426.551	.000515	.08051
	651	0.515	0.9836	781.346	.001259	.10797
	659	0.965	1.8430	795.164	.002318	.13234
438-	555	1.185	2.2632	946.138	.002392	.13374
	571	0.945	1.8048	929.175	.001942	.12477
	579	1.700	3.2468	862.406	.003765	.15557
	595	0.845	1.6138	883.476	.001827	.12224
	603	1.535	2.9316	1,703.196	.001721	.11984
	611	0.350	0.6685	1,001.701	.000667	.08739
	627	2.005	3.8293	1,208.808	.003168	.14686
	659	0.800	1.5279	1,305.337	.001170	.10537
	667	0.520	0.9831	2,171.444	.000457	.07705
486-	283	0.100	0.1910	69.532	.002747	.14005
	563	1.010	1.9290	475.928	.004053	.15944
	571	1.095	2.0913	847.752	.002467	.13512
582-	259	0.065	0.1241	40.434	.003070	.14534
	267	0.125	0.2387	84.772	.002815	.14122
	659	0.360	0.6875	150.002	.004584	.16611
654-	275	0.135	0.2578	117.744	.002190	.12986

APPENDIX

IX

US ARMY

TEST & EVALUATION COMMAND

U.S. ARMY TEST & EVALUATION COMMAND

USATECOM PROJECT NO. 5-4-3001-01

FINAL REPORT
OF INTEGRATED ENGINEERING/SERVICE TEST
OF
AN INTERIM DEFOLIANT SYSTEM CONDUCTED JOINTLY
BY THE U.S. ARMY AND U.S. AIR FORCE, PART III (U)

DA PROJECT NO. 1B543603D432

MAY 1965 R 432

DUGWAY PROVING GROUND
DUGWAY, UTAH

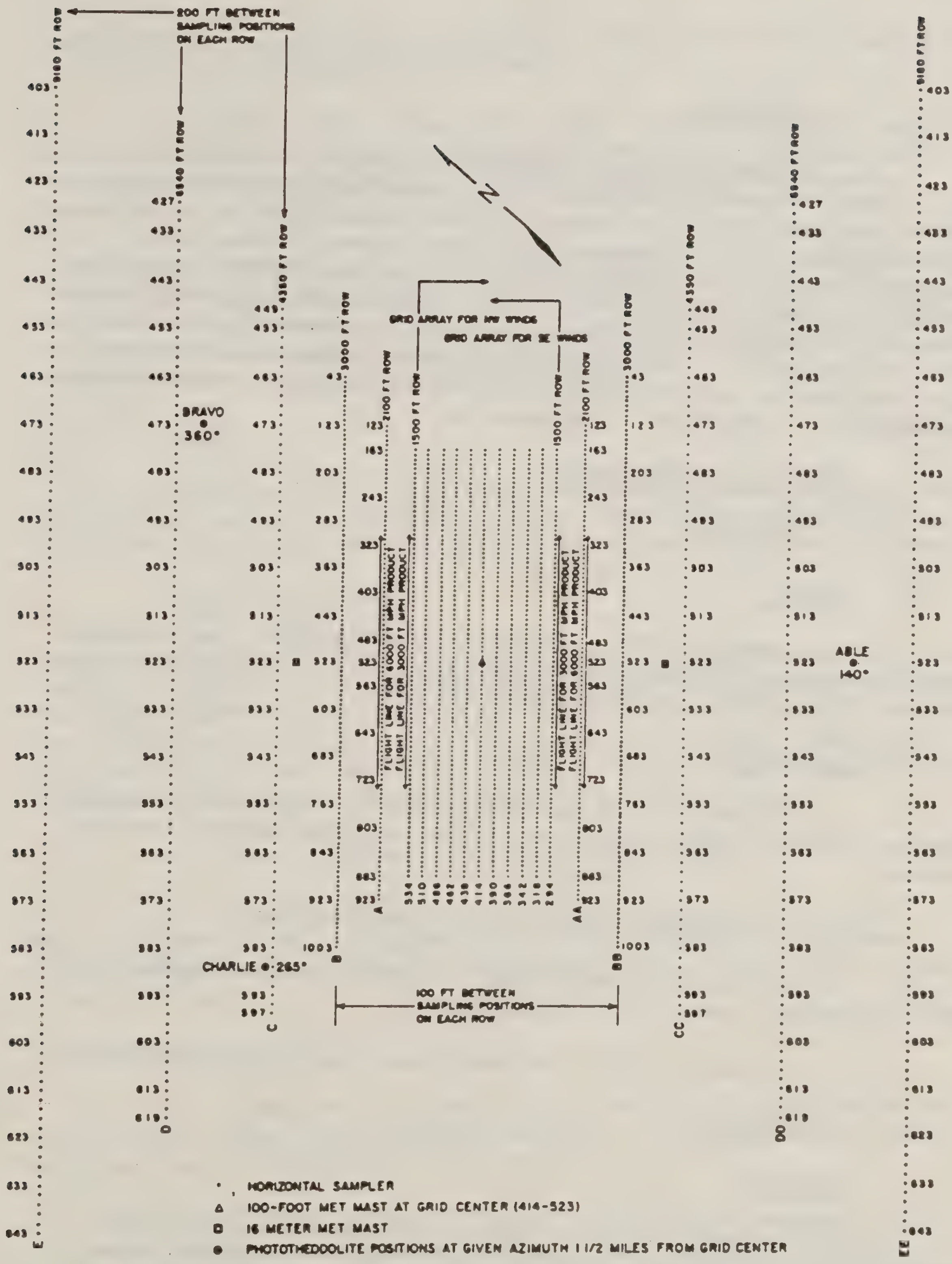

Figure 1 Two-directional Grid for C432

DISCUSSION

In planning the dissemination phase of engineering testing, a decision was required as to the combinations of release height and wind speed that minimized the probability of unsatisfactory spray tank performance going undetected. These were selected to insure sufficient separation of the droplets to allow their sizing and counting. With the droplet spectrum, settling rates can be calculated, allowing a general mathematical description of the system. It was thus decided to obtain the droplet size data and to use available theoretical techniques to determine contamination density and area coverage.

CHEMICAL DISSEMINATION

OBJECTIVES

Primary

To determine if the performance reliability, maintenance requirements, and suitability of the Army Interim Defoliant System for the OV-1 (MOHAWK) aircraft meet the SDR.

2.1.1.2 Secondary

a. To obtain data for prediction of contamination densities and area coverages for a variety of release heights and wind speeds.

b. To determine mass-droplet size spectra.

c. To obtain liquid agent recovery data from horizontally positioned samplers at ground level.

d. To measure the flow rate resulting from two settings.

METHOD

Munition

a. On each trial, one spray tank was attached to the pylon at wing station 185 on each wing of an OV-1 (MOHAWK) aircraft. The flow rate of the spray tanks was preset before each trial. On Trials 1, 2 and 3, all 32 nozzles were used for maximum

tank flow rate. On Trials 4, 5 and 6, every other nozzle was used, a total of 16, reducing the flow rate.

b. The agent-filled tanks were stored at ambient temperature in the hangar until just before spray time. Thermocouples were installed on the tanks to measure temperature of agent at spray time.

c. On each trial, each spray tank was weighed before and after filling and after release of the agent. The amount of material used and the amount of material remaining in the spray tank was recorded. A sample from the dyed agent lot used to fill the spray tanks was supplied to the laboratory.

Agent

Approximately 160 gallons, 75 to 80 gallons per spray tank (363 to 387 kg), was required for each trial. The agent fill was dyed with 6 grams of Du Pont Oil Red (C.I. 258) per liter of agent.

Flight Procedures

a. Release Height: The release height selected was such that the product of the release height (feet) and wind speed (mph) would approximate 6,000 feet miles per hour for the 600 gpm trials, and 3,000 feet miles per hour for the 400 gpm trials. These products insured droplet separation. The flight line and release height were determined by the Test Officer in the field.

b. True Air Speed: 200 knots (230 mph).

c. Flight Line Requirement: Flight and aiming point markings were installed before each trial to indicate the line of flight, aiming point, point of discharge and cut-off point as indicated in Figure 1.

Photographic

a. Documentary motion pictures and still photographs were taken of the spray tank filling operations, the spray cloud during emission, and subsequent downwind travel.

b. Emission altitude, length of emission, emission time, discharge point in relation to the grid, and speed and line of flight of the aircraft were obtained from phototheodolites located at three positions.

c. On all trials, the contaminated Printflex cards were microfilmed. To permit droplet size stabilization, the cards were

not photographed until 24 hours after each trial. To minimize fading of the dye in the agent, the contaminated cards were stored in a dark room.

Sampling

On all trials, one horizontally positioned, ground level Printflex card (size 6 by 7 inches) and one filter-paper sampler were placed at each of the positions indicated in Figure 1. The filter-paper sampler (consisting of three layers of E & D Number 618 filter paper with an exposed area of 143.7 square centimeters) and the Printflex cards were attached, side by side, to stainless steel holders.

Meteorological

a. On each trial, one 30-meter profile mast, and two 16-meter masts were installed on Downwind Grid as indicated in Figure 1. In addition, one meteorological station was installed immediately upwind of the spray release line to obtain pibal data and other required observations.

b. Meteorological data was measured and reported in accordance with Meteorology Division SOP NO. 1, subject: "The Processing of Field Test Meteorological Data," dated 22 August 1962. The pibal data was used to obtain the mean wind direction and speed from surface to release height.

Laboratory

a. Following each trial, all filter papers were detached from their holders and returned to the laboratory where the filter papers were assayed by ultra violet spectrophotometry. This method of analysis showed greater sensitivity than the colorimetric method called for in the test plan DPGTP C432 (Reference b, Part I).

b. The control samples from each dyed agent lot were used by the laboratory for the preparation of standards for the analytical assay of each trial.

c. The microfilm negatives of the contaminated Printflex cards, obtained on each trial, were forwarded to the laboratory for a mass-droplet size spectra determination. An Automatic Spot Counter and Sizer (ASCAS) was used to optically scan a 9- by 9-millimeter area of the film and compute the number of droplets in each of ten size categories for each Printflex card. From these data a mass median diameter (mmd) was determined for each trial. A complete description of the equipment and the methodology used in

making the mmd determination is contained in Dugway Summary Report 64-10 (Reference h, Part I).

RESULTS

Munition

a. The amount of agent disseminated on each trial is shown in Table 1.

Table 1 Agent Dissemination Data for C432

TRIAL NUMBER	AMOUNT OF AGENT DISSEMINATED				TOTAL	
	Left Tank		Right Tank[a]			
	pounds	kilograms	pounds	kilograms	pounds	kilograms
1	NA[b]	NA	NA	NA	NA	NA
2	465.5	211.2	467.0	211.8	932.5	423.0
3	471.0	213.6	533.5	242.0	1004.5	455.6
4	327.5	148.6	465.5	211.2	793.0	359.8
5	334.0	151.5	24.0	10.9	358.0	162.4
6	352.0	159.7	370.5	168.1	722.5	327.8

[a]Forward coupling hose from pump ruptured on Trial 4. Gate valve only partially opened on Trial 5.

[b]Not available, refer to paragraph b, below.

Agent Recovery

The agent recovery, that is, the weight of liquid agent accounted for within the sampling array, was used as a rough measure of tank efficiency. Agent recoveries are based on the chemical analysis of the horizontal filter-paper samplers. Filter-paper contamination densities, in milligrams per square meter, were converted to a total recovery estimate using the point-count method. In this technique, area coverage is ascertained by assigning fixed areas to each sampler and assuming that the sample recovered is representative of the average contamination over the area assigned for that sampler. A summary of agent recovery data is given in Table 3; complete data are presented in Appendix I. On Trial 1, the spray release mechanism was activated erratically and no recovery estimates were obtained.

Spray Tank Flow Rate

Spray tank flow rates were estimated from graphs. The liquid recoveries, in gallons, for the first several downwind rows showing average contamination densities of at least 100 mg/m^2,

Table 3 Liquid Agent Recovery Data for C432

TRIAL NUMBER	AMOUNT OF AGENT DISSEMINATED (gm)	AMOUNT OF AGENT RECOVERED (gm)	ESTIMATED AGENT RECOVERY (%)
2	422,975	359,753	85.1
3	455,634	470,516	103.3
4	359,699	364,110	101.2
5	162,386	158,474	97.6
6	327,721	281,247	85.8

were plotted cumulatively against the crosswind distance represented, in meters. From the speed of the aircraft, the crosswind distance was converted to dissemination time, in seconds. The slope of the line, in gallons per second, was then used as the estimate of average flow rate. These estimates are shown in Table 4.

Table 4 .. Spray System Flow Rates (Two E44 Tanks) for C432

TRIAL NUMBER	SETTING[a]	ESTIMATED FLOW RATE			
		gal/sec	kg/sec	gal/min[b]	kg/min
2	Full	11.8	57.1	708.0	3426.0
3	Full	11.6	56.1	696.0	3366.0
4	Half	7.0	33.9	420.0	2034.0
5	Half	7.0	33.9	420.0	2034.0
6	Half	7.0	33.9	420.0	2034.0

The flow rate specification requires that "the maximum flow rate of the system [two E44 spray tanks] shall be at least 600 gallons per minute, and lower rates shall be selectable by ground adjustment." Table 4 data show that this requirement was met.

Table 5 .. Summary of Meteorological Data for C432

TRIAL NUMBER	2-METER WIND		30-METER WIND		2-METER AIR TEMPERATURE (°F)	2-METER RELATIVE HUMIDITY (%)	TEMPERATURE GRADIENT (F°)	MEAN WIND SPEED[a] (mph)
	Direction (°)	Speed (mph)	Direction (°)	Speed (mph)			0.5 to 30 m	
1	340	2.8	343	6.6	63.0	26	3.8	9.0
2	328	8.4	335	11.2	74.1	22	0.6	22.0
3	311	3.1	308	4.6	76.0	21	0.3	9.8
4	079	1.7	177	12.5	51.8	40	>10.0	14.9
5	125	5.5	147	8.1	52.0	35	5.5	17.3
6	265	4.4	277	6.6	79.1	19	0.1	9.0

[a]Mean wind from surface to release height obtained from pibal data.

2.1.3.4 Meteorological

A summary of the general meteorological conditions existing during spray release is given in Table 5. Complete meteorological data are on file at DPG.

2.1.3.5 Droplet Spectra

a. The number and size of the droplet stains appearing on each Printflex card were determined for Trials 2, 3, 5 and 6. No droplet data were obtained on Trials 1 and 4. From these counts, the mass median diameter of the droplet cloud was calculated. The results are shown in Table 6. On both of the trials using full flow rate, the criterion of the TTC, that the cloud have a mass median diameter lying between 250 and 300 microns at an aircraft speed of 200 knots, was satisfied. On the two trials at half flow, that is, with half of the dissemination nozzles operating, the mass median diameter was slightly less than 250 microns. It was, however, large enough to insure rapid fall-out of the droplet cloud. As shown by Table 6 data, performance of the system with respect to specified droplet size was thus satisfactory.

Table 6 . Mass Median Diameter Determinations For C432

TRIAL NUMBER	MASS MEDIAN DIAMETER (Microns)	NUMBER OF NOZZLES
2	285	32
3	260	32
5	227	16
6	202	16

b. All droplet data were reduced using an Automatic Spot Counter and Sizer (ASCAS). This machine uses optical contrast to scan the microfilm negatives of the contaminated Printflex cards, and determines the total number of stains in each of ten stain-size increments. Stain sizes are converted into droplet diameters using a digital computer, which assigns a stain-to-droplet conversion factor for each increment. After that conversion, the computer calculates that droplet diameter having one-half of the

total mass accounted for by larger diameter droplets and one-half by smaller droplets, that is, the mass median diameter.

Flight Results

Spray release data, obtained photographically, are summarized in Table 7.

Table 7 Flight Data for C432

TRIAL NUMBER	RELEASE HEIGHT[a] (feet)	AIRCRAFT SPEED (feet/sec)	DISSEMINATION TIME[b] (sec)
1	740	335	-[c]
2	350	335	11.8
3	700	315	14.3
4	270	310	17.7
5	240	315	17.6
6	450	310	17.9

[a]Data given for midpoint of dissemination line.

[b]End point includes calculation to point of visible trail-out.

[c]No computations were made.

Area Coverage

a. As indicated above, all dissemination tests were designed to minimize the probability of unsatisfactory performance going undetected. Accordingly, on all trials the spray release height was selected to insure a distinct separation of droplets, which was needed to insure accurate size and mass distribution measurements. These measurements were required for two reasons. First, they allowed the conclusive demonstration that the droplet mass median diameter was between 250 and 300 microns, a TTC requirement (see paragraph 2.1.3.5, above). Second, they provided performance data needed to select and refine a prediction equation relating system effectiveness, which in this case was area coverage at contamination densities exceeding 3 gallons per acre, and the three operational deployment parameters, release height, wind speed, and flow rate.

b. The mathematical analysis is discussed in detail in paragraph 2.1.4, below. As shown there, an excellent agreement between observed and predicted results was obtained. Area coverage for two flow rates and five combinations of height and wind speed were then calculated. The results are shown in Table 8.

c. It was on the basis of Table 8 calculations that the spray system was found satisfactory when judged against the SDR requirement that the two-tank system " . . . be capable of depositing up to three gallons of agent per acre of target area," as well as the TTC requirement that "the spraying system shall be designed so as to provide a deposition rate of up to 3 gallons per acre over an area of approximately 17 acres."

ANALYSIS

Introduction

The analysis required to demonstrate the satisfactory performance of the spray system consisted of the straight forward presentation of data with respect to two of the three criteria, the droplet size distribution at an air speed of 200 knots and the maximum flow rate criterion. Demonstrating that area coverages as great as 17 acres would be contaminated at densities as great as 3 gallons per acre required considerable analytical study. The computational procedures followed are discussed in this section.

Area Coverage Analysis

Statement of the Problem--The problem was to predict the area coverage of the spray system at contamination densities of up to 3 gallons per acre, or 3.5 grams per square meter, from field data giving actual area coverage at contamination densities of 0.7 grams per square meter, one-fifth the desired amount.

Technical Approach--Three graphical solutions to the general differential equation for atmospheric diffusion and settling[1] were found by substituting field test data into the equation

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[1]An excellent outline of the approach followed in this analysis is given by Pasquill, Atmospheric Diffusion, New York: D. Van Nostrand Company Ltd., 1962. pp. 229 ff.

Table 8a Area Coverage Estimates and Swath Widths, in English Units, for the Defoliant System

FLOW RATE (gpm)	DISSEMINATION LINE (feet)	RH-WS[a] PRODUCT (ft-mph)	CONTAMINATION DENSITIES			
			3 Gallons/Acre		1.5 Gallons/Acre	
			swath width (feet)	area coverage (acres)	swath width (feet)	area coverage (acres)
300	10,720	500	93.8	23.1	141.9	34.9
		750	89.3	22.0	171.7	42.2
		1000	36.4	9.0	187.5	46.1
		1500	0.0	0.0	178.5	43.9
		2000	0.0	0.0	73.5	18.1
600	5,360	500	141.9	17.5	187.5	23.1
		750	171.6	21.1	241.1	29.7
		1000	187.4	23.1	283.5	34.9
		1500	178.4	22.0	343.2	42.2
		2000	73.2	9.0	373.3	45.9

[a]Release height-wind speed product.

Table 8b Area Coverage Estimates and Swath Widths, in Metric Units, for the Defoliant System

FLOW RATE (kg/sec)	DISSEMINATION LINE (m)	RH-WS[a] PRODUCT (m-m/sec)	CONTAMINATION DENSITIES			
			3.5 grams/m^2		1.75 grams/m^2	
			swath width (m)	area coverage (ha)	swath width (m)	area coverage (ha)
25.55	3,267	68.13	28.6	9.3	43.3	14.1
		102.19	27.2	8.9	52.3	17.1
		136.26	11.1	3.6	57.1	18.7
		204.39	0.0	0.0	54.4	17.8
		272.52	0.0	0.0	22.4	7.3
51.10	1,634	68.13	43.2	7.1	57.2	9.3
		102.19	52.3	8.5	73.5	12.0
		136.26	57.1	9.3	86.4	14.1
		204.39	54.4	8.9	104.6	17.1
		272.52	22.3	3.6	113.8	18.6

[a]Release height-wind speed product.

and solving for the remaining unknowns. The curves obtained are shown in Figures 2, 3, and 4. In the predictions of area coverage, shown in Table 8, the curve 2 equation was used. This equation, identified by Pasquill[2] as the Rounds-Godson equation, rests on three key assumptions, all valid in this case.

a. X_{max}, the downwind distance to the line of maximum concentration, is a linear function of the height-wind speed product;

b. A single average value can be used for the settling velocity of the droplet cloud; and,

c. The droplets are sufficiently large to overcome the drifting associated with changes in atmospheric stability.

The equation used in fitting curve 2 was a simplified form of the Rounds-Godson equation,

$$C(X) = \frac{Q}{f\Gamma(p)}\left[\frac{f}{X}\right]^{p+1} \exp -(f/X),$$

where X is downwind distance (meters), C(X) is the average contamination density at that distance (grams per square meter), Q is average source strength (grams per meter), f is the operational parameter proportional to the release height wind speed product, p is the droplet parameter proportional to the settling velocity, and Γ is the gamma function

$$\Gamma(p) = \int_0^\infty x^{p-1} e^{-x}\, dx.$$

The parametric values obtained in fitting curve 2 are shown in Table 9.

Table 9 (UNCLASSIFIED). Derived Constants Used in Curve 2 Analysis (U).

TRIAL	f	p
2	2,194.56	5.0
3	2,789.78	6.2
6	1,691.40	5.0

[2]Pasquill, op. cit., pp. 229-230.

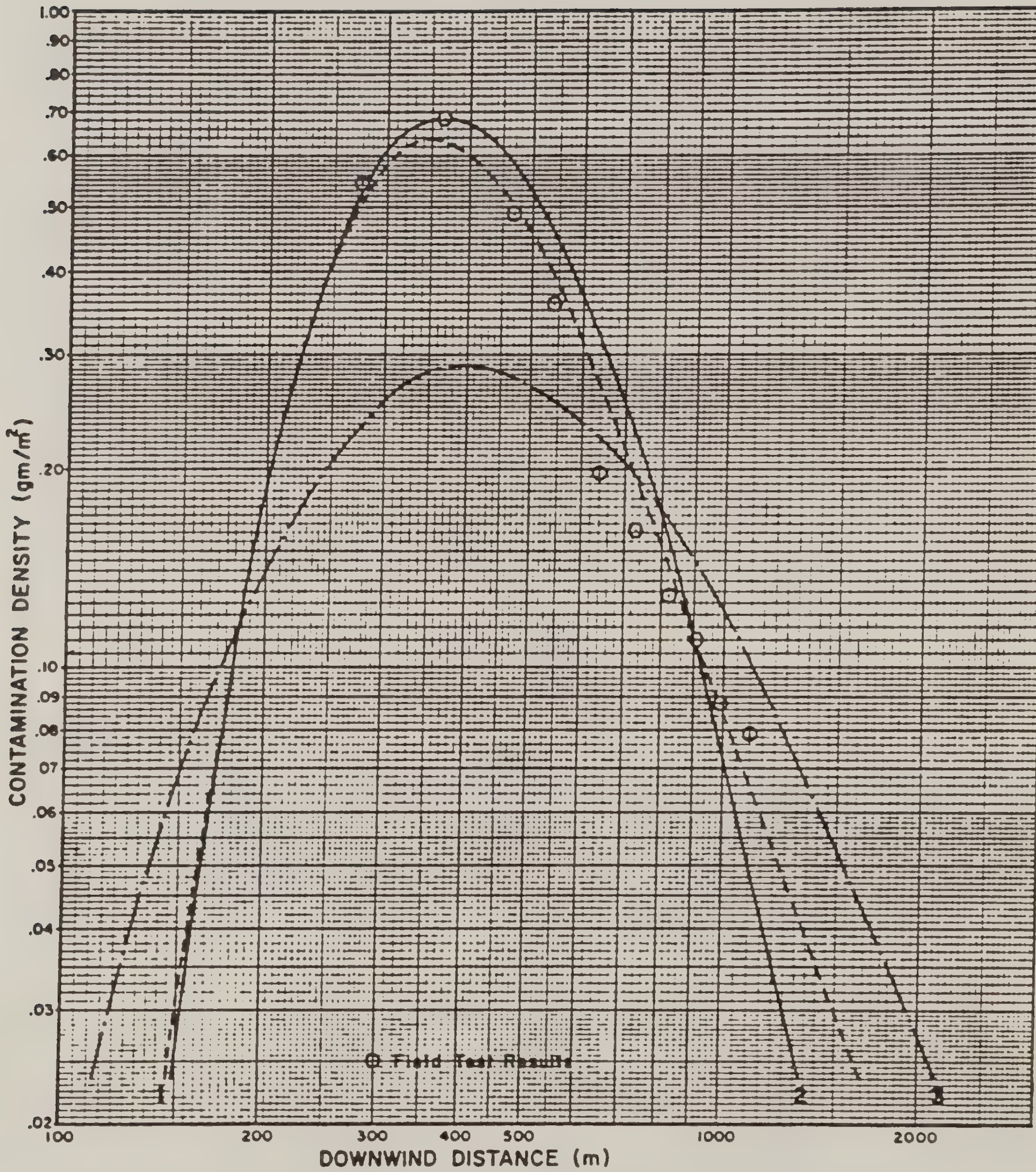

Figure 2 Average Contamination Density as a Function of Downwind Distance for Three Diffusion Models, C432, Trial 2

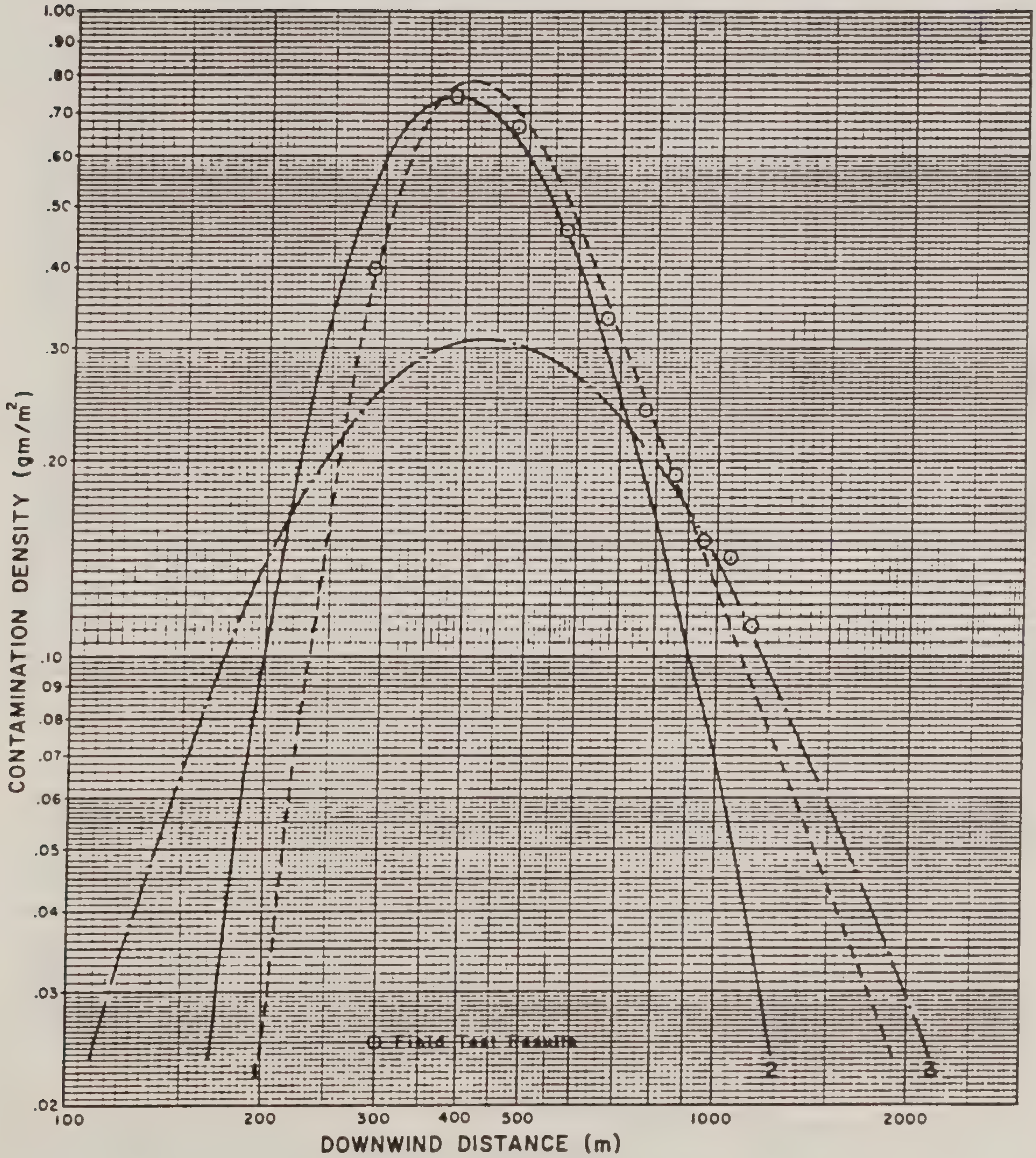

Figure 3 Average Contamination Density as a Function of Downwind Distance for Three Diffusion Models, C432, Trial 3

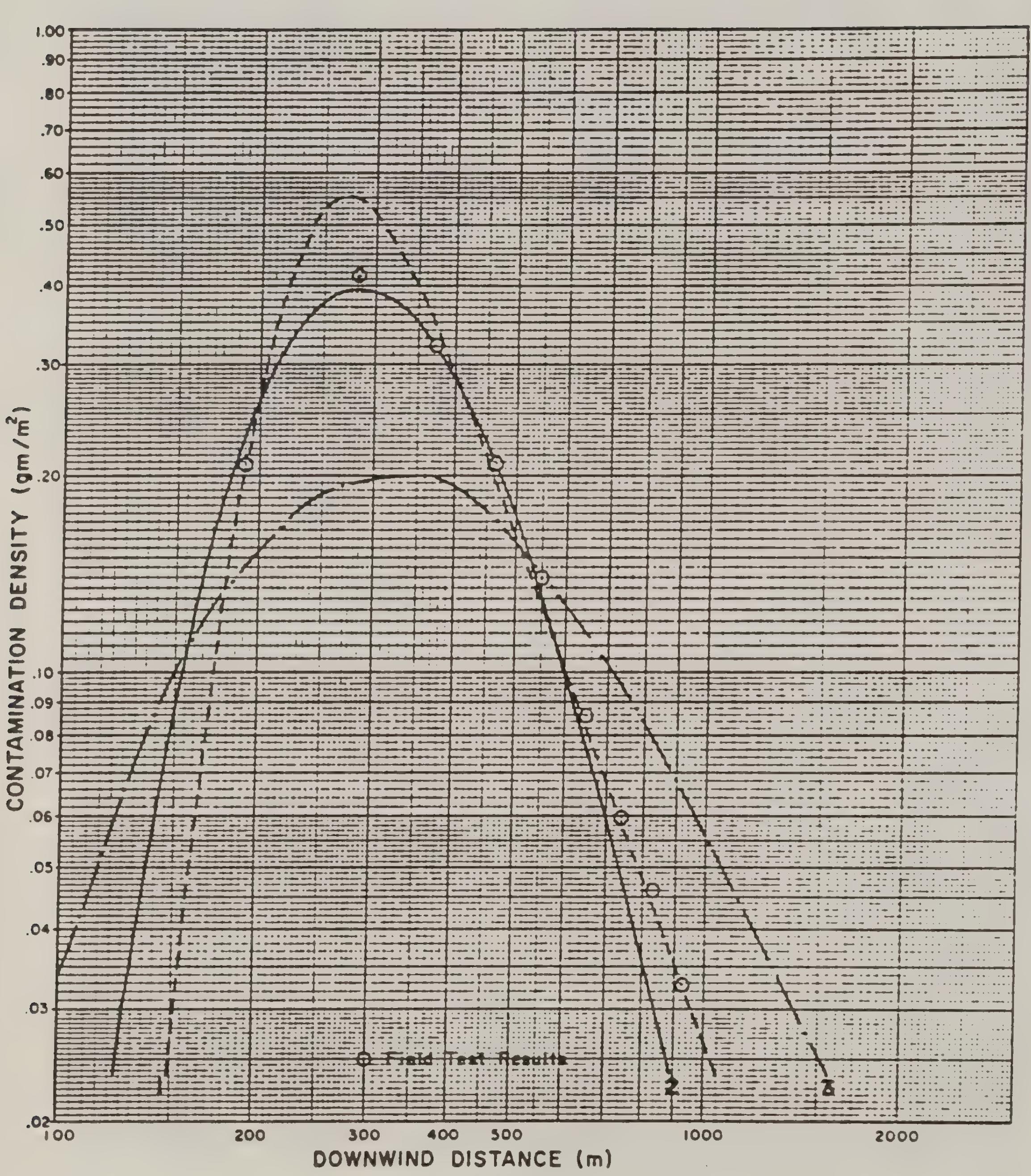

Figure 4 Average Contamination Density as a Function of Downwind Distance for Three Diffusion Models, C432, Trial 6

Area Coverage Estimates

Area coverage estimates were obtained in a straightforward manner from the above equation. The value of p was taken as a constant, 5.48, corresponding to the assumption that the observed droplet diameter distribution will be generally constant. The value of f, which was taken as proportional to the release height-wind speed product, changed for each combination of release height and wind speed for which predictions were made. The relationship used in calculating the area coverage and swath width predictions of Table 8 was based on an f equal to 2.6467 times the release height-wind speed product, or,

$$f = 2.6467\ (RH \times \overline{U}).$$

With values of f and p established, the calculation of tables needed to establish swath width and area coverage was accomplished on a digital computer. Typical curves are shown in Figures 5 and 6. From these curves, the swath width, X, at a given contamination density, Y, can be directly read as the interval between the ascending and descending portion of the curve. All values shown in Table 8 were derived by an analogous procedure. Area coverage estimates were then made by multiplying swath width times the length of the release line.

Performance Reliability

a. With correction of minor mechanical difficulties, performance reliability, defined by the SDR as the probability of effective dissemination of agent on target, will be determined by the combined effect of release height and wind speed. Release height can be selected. The remaining variable will then be the ratio between the wind speed estimate available to the pilot and the wind speed encountered by the droplet cloud. As that ratio approaches unity, the probability of hitting the target effectively will approach 100 percent.

b. The accuracy with which effective wind speed can be predicted varies widely. It is a function of climate, terrain, and season as well as the general meteorological survey data available. For that reason, establishing compliance with the SDR paragraph specifying system reliability was beyond the scope of this test. The extremes of height and wind speed for the system are shown in Table 8. The prevalence in a specific operational theatre of effective wind speeds, as well as the accuracy with which these can be predicted must be established in the field, allowing selection of spray missions under conditions for which system reliability is a maximum.

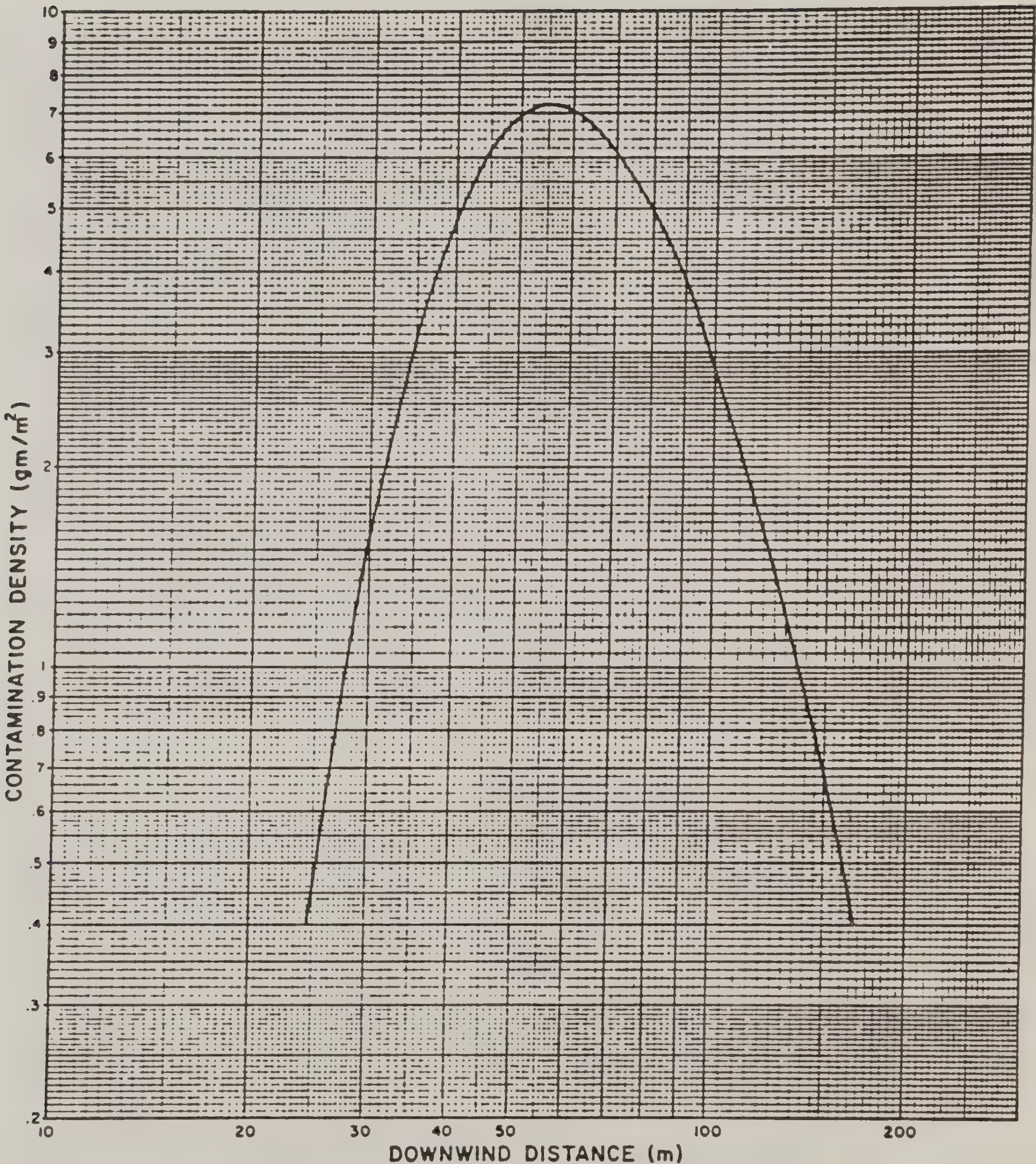

Figure 5 Contamination Density as a Function of Downwind Distance for a Flow Rate of 600 Gallons per Minute and a Release Height-Wind Speed Product of 1,000 feet-mph

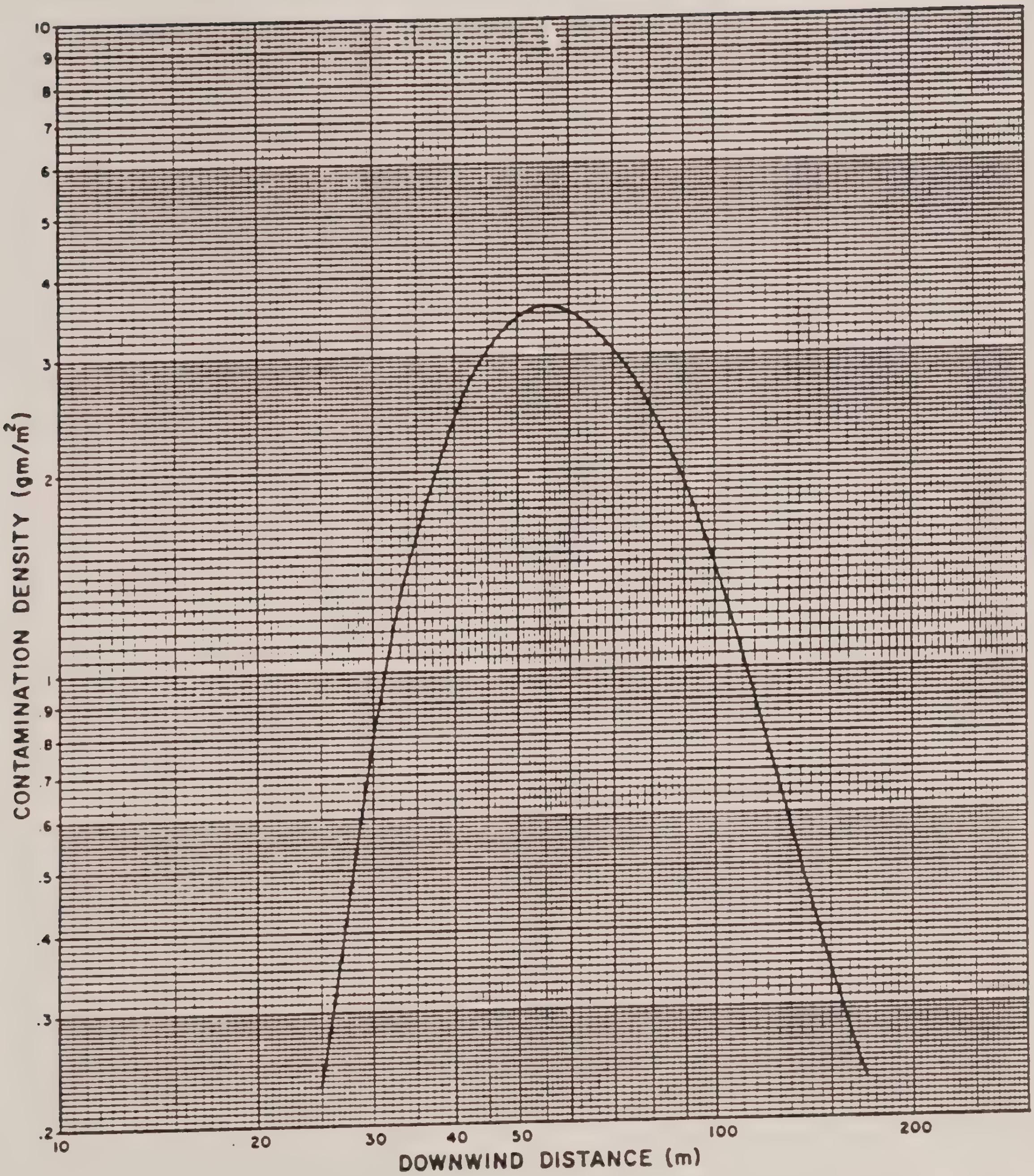

Figure 6 Contamination Density as a Function of Downwind Distance for a Flow Rate of 300 gallons per minute and a Release Height-Wind Speed Product of 1,000 feet-mph

APPENDIX

X

RDT&E PROJECT NO. 1D522301A196-02
USATECOM PROJECT NO. 5-6-3140-01

DPG PROJECT NO. C679

DPG-I-

FEASIBILITY TEST OF THE E44 CS
SPRAY TANK ON OV-1 MOHAWK AIRCRAFT

DATA REPORT

BY

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AUGUST 1966

DUGWAY PROVING GROUND
DUGWAY, UTAH

INTRODUCTION

Preliminary Sampler Investigation

Early in the test program, a series of wind tunnel studies was completed to evaluate the effects of sampler orientation on collection efficiency and to determine if trace amounts of methylene chloride lowered the reliability of the chemical analysis. Two types of samplers were investigated, the snoot sampler and the 6-15 All Glass Impinger. The criticality of sampler orientation with respect to the prevailing wind direction was confirmed. At orientation angles exceeding 30 degrees, recoveries fell off sharply. Trace amounts of methylene chloride showed no measurable effect on the reliability of the chemical analysis.

Field Test Program

This feasibility test was conducted in accordance with Reference 2, and consisted of nine trials divided into two phases. On Phase A, six tower fly-by trials were conducted to define the possible effects of agent solution concentration-spray boom orientation on the effective dispersal of the agent payload. Phase B consisted of three trials using the fly-by tower augmented by a horizontal downwind sampling array. The program was conducted as outlined in Table 1.

CHEMICAL DISSEMINATION

Objectives

The objectives of this test were:

a. To determine the dissemination efficiency of the system for the total and inhalable agent return recovered by samples on the 96-meter tower.

Table 1. Test Outline for C679.

TRIAL NUMBER	NUMBER OF SPRAY TANKS USED	PERCENT CS IN SOLUTION	ORIENTATION OF SPRAY BOOM[a] (°)	NOMINAL AIRCRAFT SPEED (knots)	NOMINAL SPRAY RELEASE HEIGHT (m)
A-1	1	10	0	200	60
A-2	1	10	90	200	60
A-1R[b]	2	10	0	175	60
A-2R[b]	2	10	90	175	60
A-3	2	20	0	225	60
A-4	2	20	90	225	60
B-1	2	20	0	200	30
B-2	2	20	0	200	30
B-3	2	20	0	200	30

[a]The orientation of the spray boom with respect to the horizontal line of flight.
[b]Trial was repeated.

b. To obtain a qualitative characterization of the vertical particle size distribution of the agent cloud from cascade impactor samplers on the 96-meter tower.

c. To determine area coverage from samplers positioned 1.5 meters above the ground adequate to define the dosage 10 contour.

Method

Munition. Munition procedures were as follows:

a. Agent Preparation. The agent used on these trials was prepared in a mixing vessel, equipped with temperature control and powered stirrer, in 605.6-liter (160-gallon) batches. The 10-percent solution was prepared by dissolving 79.8 kilograms (176 pounds) of CS in 718.5 kilograms (1,584 pounds) of methylene chloride. The 20-percent solution was prepared by dissolving 159.6 kilograms (352 pounds) of CS

in 638.6 kilograms (1,408 pounds) of methylene chloride. The solution was agitated for about one hour. Samples were withdrawn at 15-minute intervals and viscosity measurements made to assure homogeneity of the solution.

b. Filling Procedure. The solution was transferred from the mixing vessel into the E44 tank using a pipe connected from the outlet of the mixing vessel to the tank filling port. The closed system was pressurized to 5 psi to permit ease of liquid transfer. Thermocouples were attached to the outlet of the mixing vessel and the skin of the tank being filled to monitor fluid and ambient temperatures during the filling process. Prior to filling, the tank was given a functional check and weighed. The tank weight was carefully monitored during the filling process to insure that the flight certified weight of 487.6 kilograms (1,075 pounds) was not exceeded. The weight of the full tank was recorded.

c. Aircraft Mounting. Each tank was mounted to the standard 14-inch lugs under the wing of the OV-1 aircraft. The tank was given a functional test (to assure proper operation of the gate valve) and then pressurized to 2 psi. After the mission was completed, the tank was weighed to determine the amount disseminated.

d. Tank Pressure Instrumentation. On Trials B-2 and B-3, two pressure transducers were installed on Tank No. 2 to measure boom and tank pressures during the dissemination. A 0- to 50-psi transducer was connected to the end of the spray boom, with a $\pm$7.5-psi transducer connected to the tank. Both instruments were calibrated prior to the flight and pressures were recorded during dissemination.

Flight Path. On each trial, the aircraft passed approximately 91 meters (300 feet) upwind of the 96-meter tower on a line approximately normal to the prevailing wind direction. The nominal aircraft speed, height, and other pertinent information relative to the mission are given in Table 1. The pilot reported instrument speed, height and bearing along with pertinent observations for each trial.

Meteorological. On each trial, wind direction, wind speed, temperature gradient and bivane data were measured on the 96-meter profile mast (the fly-by tower). On each Phase B trial, three portable 2-meter masts were located 200, 1,000, and 2,000 meters downwind of the 96-meter tower along the prevailing wind direction. The 2-meter wind direction and speed were recorded at these portable mast locations. Data from the profile mast were telemetered to the meteorological van, located approximately 500 meters from grid center on an azimuth of 140 degrees. Data at the portable stations were recorded locally and retrieved after the trial was completed. Other pertinent surface and upper air observations were recorded at the meteorological van.

Sampling. The sampling procedures were as follows:

a. Phase A:

(1) The 96-meter tower was instrumented with one impinger and one snoot sampler at 2-meter intervals from 1 through 96 meters. On each trial, the 96 samplers were aspirated at the rate of 6 liters per minute. Aspiration was begun at Z-2 minutes and continued until the cloud passed through the tower, providing data at each 2-meter interval from 1 to 95 meters.

(2) Nine cascade impactor samplers were positioned at 10 meter intervals from 10 through 90 meters and aspirated at the rate of 17.5 liters per minute from Z-2 minutes until the cloud passed through the tower.

b. Phase B:

(1) One impinger and one snoot sampler were positioned at 2-meter intervals at each of 48 stations on the tower and aspirated at 6 liters per minute from Z-2 minutes until the agent cloud passed through the tower.

(2) Cascade impactor samplers were positioned at 10-meter intervals from 10 through 90 meters on the tower. The samplers were aspirated at the rate of 17.5 liters per minute from Z-2 minutes until the agent cloud passed through the tower.

(3) One BC sequential sampler was positioned at each of the 440 positions shown in Figure 2, with the intake of the bubblers 1.5 meters above the ground. Each sampler was equipped with five impingers and aspirated at the rate of 6 liters per minute in accordance with the following schedule:

Bubbler Number	Sampling Interval (minutes)
1	Z[a] - 2 to Z+ 1
2	Z + 1 to Z+ 5
3	Z + 5 to Z+10
4	Z +10 to End of test

[a]Z denotes emission time.

Field controls were taken upwind of the flight line.

(4) One impinger bubbler was positioned 4.5, 9.1, 13.7, 18.2, 22.8, and 27.4 meters above the ground (15, 30, 45, 60, 75, and 90 feet) on each of six towers shown in Figure 2. These towers were

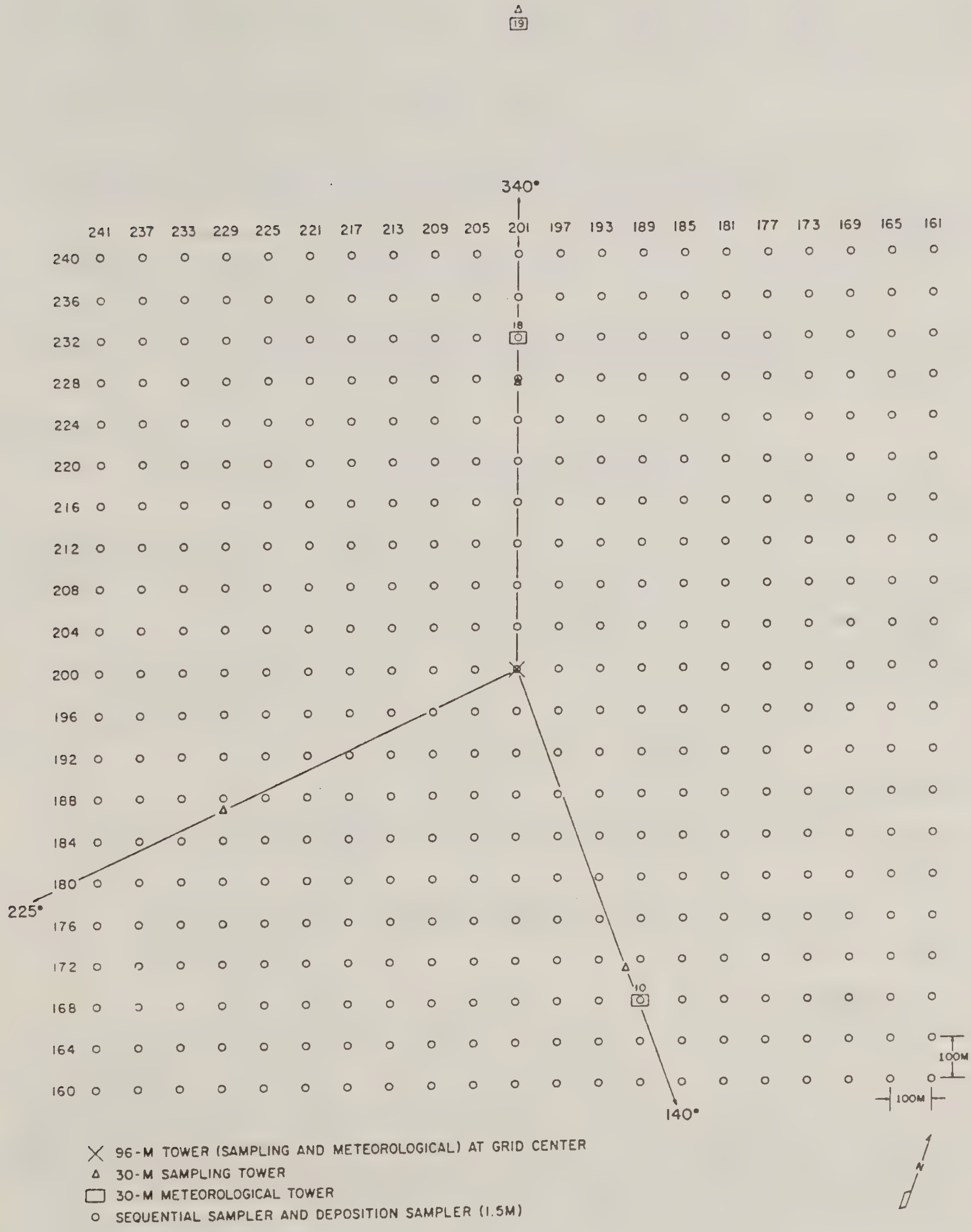

Figure 2. Grid Diagram for C679.

used to provide supplemental data on the vertical dosage profile downwind of the 96-meter tower on trials on which these towers fell in the path of the agent cloud.

(5) Deposition samplers were located as shown in Figure 2.

(6) Following each mission, the aircraft was inspected for visible signs of contamination. Representative areas were swabbed and identified.

Photographic. The photographic procedures were as follows:

a. Motion picture coverage was provided from upwind and flank positions to record the agent cloud traversal through the tower on all trials.

b. Three cinetheodolite positions were used to obtain discharge altitude, length of discharge, discharge time, discharge point in relation to the grid, and aircraft speed and line of flight.

c. Documentary motion pictures and still photographs were taken of agent preparation, filling operations, aircraft loading operations, emission spray line, visual effect of spray upon samplers, and decontamination operations.

Laboratory. The laboratory procedures were as follows:

a. A quantitative analysis was made separately on the contents of each impinger bubbler for agent CS.

b. Each stage of each cascade impactor sampler was analysed separately for the quantitative amount of agent CS.

c. Agent content by weight and the viscosity of the agent solution were determined on samples drawn from each agent batch.

Results

Munition. The munition results were as follows:

a. Agent Preparation. All agent solution was prepared as described in paragraph 2.2.2.1,a. CS Agent Lot Number 2013-43-124 and Methylene Chloride Lot Number NG-46 were used to prepare all agent solution for this test. Pertinent data, including solution temperatures and ambient air temperatures, are listed in Table 2.

Aircraft and Flight. The CV-1/E44 spray system was operated at speeds of 87 to 115 meters/second (169.0 to 223.4 knots), and emission heights of 27 to 64 meters (88.6 to 209.9 feet) above terrain. Both single-tank and dual-tank emissions were achieved. A summary of operational data is presented in Table 5.

Meteorological. A summary of the meteorological conditions existing at or near spray release time is presented in Table 6. The continuous chart recordings obtained for the bivanes on Trials A-1R, A-3, B-1, B-2, and B-3 were processed. On the Phase A trials, these data were reduced to means and standard deviations of elevation angles based on a 2.5-minute averaging time for a 10-minute period. On the Phase B trials means and standard deviations of azimuth and elevation angles were reduced from the charts at 2.5-minute averaging times for a 10-minute period. All data were forwarded to the test sponsor. Complete data are on file at DPG and copies may be obtained upon request.

Sampling. Sampling results were as follows:

a. Preliminary Studies. A series of wind tunnel trials were conducted to estimate the general limitations of snoot and impinger samplers under field conditions.

(1) Trials were conducted at three nominal wind speeds, 4, 8, and 12 mph, giving three points on the wind speed-collection efficiency curve for each device. Recoveries, uncorrected for fallout upwind of the sampling station, are shown in Table 7. Table 7 also shows the standard deviation for the recovery data obtained.

(2) The fallout sampler selected was a piece of polyethylene sheeting coated with a 10-percent solution of low density polyisobutylene in benzene. This sampler gave a qualitative indication of agent fallout.

b. Field Test Sampling Results. Results obtained on the field tests were as follows:

(1) Tower Recovery Results. Four trials were used to estimate weapon efficiency (Trials A-1R, A-3, B-1, and B-3). On the two single tank/10-percent solution trials (A-1 and A-2), flow rates were 8.2 and 9.4 grams per meter. All dosages fell below the sensitivity of the chemical analysis. On two trials (A-2R and B-2), sudden changes in wind direction, together with thermal turbulence, resulted in the collection of extremely scattered data. No recovery calculation was attempted. On Trials A-2R and B-2, the shift in wind direction with respect to the sampler orientation exceeded $\pm 30°$, the upper limit for the type sampler used. A summary of the tower results is presented in Table 8. On Trial A-4, no data were obtained.

Table 5. Summary of OV-1/E44 System Operational Data for C679.

DATUM DESCRIPTION	TRIAL NUMBER								
	A-1	A-2	A-1R	A-2R	A-3	A-4	B-1	B-2	B-3
Aircraft Heading (°UTM)[a]	105.5	255.5	332.0	332.5	ND[b]	331.6	62	120	46.1
Aircraft Speed (m/sec)	110	100	90	87	ND	115	100	95	96
Spatial Coordinates of Aircraft with Respect to Target Center at Start of Emission									
X (meters)	970 W[c]	560 E[c]	325 E	385 E	960 E	535 S	905 W	883 W	820 W
Y (meters)	170 N[d]	0 N	805 S[d]	985 S	300 N	780 N	420 S	592 N	640 S
Z (height in meters)	62	64	62	58	64	62	58	27	30
Length of Dissemination (m)	1950	1500	1810	2050	ND	2040	2200	1885	1825
Emission Duration (sec)	18	15	20	23.7	ND	17.9	21.8	19.8	18.9
Calculated Flow Rate (gal/min)									
Tank No. 2	103.94	NA	145.08	101.73	ND	98.4	112.22	116.52	91.76
Tank No. 4	NA[e]	112.36	116.72	107.71	ND	105.53	111.99	114.44	126.99
Calculated Flow Rate (l/min)									
Tank No. 2	393.44	NA	549.20	385.08	ND	371.11	424.80	441.08	347.33
Tank No. 4	NA	425.33	441.84	407.72	ND	399.48	423.91	433.18	480.69
Effective Source Strength (g/m)[f]	8.229	9.445	22.792	19.915	ND	30.502	40.325	45.209	38.461[g]

[a] UTM is Universal Transversal Mercator.

[b] ND = No data (due to loss of binary time on the film).

[c] W = West; E = East.

[d] N = North; S = South.

[e] NA = Not Applicable.

[f] Amount of pure agent CS disseminated per unit length of dissemination line. Calculations based on an average agent purity of 94.74 percent.

[g] Accurate source strength can not be calculated because an unknown amount of agent spilled out of the air scoops during the flight.

Table 6. Summary of Meteorological Conditions for C679.

TRIAL NUMBER	1-METER AIR TEMPERATURE (°F)	STABILITY (F°)	RELATIVE HUMIDITY (%)	2-METER WIND		16-METER WIND		32-METER WIND		10-MINUTE HORIZONTAL[a] WIND DIRECTION (°)	
		0.5 to 64 m		Direction (°)	Speed (mph)	Direction (°)	Speed (mph)	Direction (°)	Speed (mph)	Mean	SD[b]
A-1	89.8	-3.2	17	215	10.6	202	9.4	196	11.2	NR[c]	NR
A-2	88.4	-3.6	15	165	10.6	150	13.6	125	16.0	NR	NR
A-1R	66.0	-3.9	37	215	3.8	210	4.8	200	4.4	NR	NR
A-2R	71.8	-7.8	23	245	5.3	265	6.7	231	INOP[d]	NR	NR
A-3	53.5	-5.2	46	317	7.4	318	12.8	320	16.6	NR	NR
A-4	73.8	-2.2	22	INOP	2.4	263	6.8	250	INOP	NR	NR
B-1	75.8	-3.7	17	315	6.2	333	10.2	316	12.0	341.532	27.935
B-2	63.7	-3.0	23	344	8.7	342	9.3	347	9.3	333.927	11.262
B-3	81.5	INOP	10	325	7.2	310	7.2	310	6.4	341.838	14.855

[a]Averages are for the 16-meter height.
[b]Standard deviation.
[c]Data was not reduced.
[d]Inoperative.

Table 7. Impinger and Snoot Sampler Recovery Data Obtained from Wind Tunnel Trials on T679.

ITEM	TYPE OF SAMPLER					
	Impinger			Snoot		
	4 mph	8 mph	12 mph	4 mph	8 mph	12 mph
Number of Trials[a]	7	11	7	10	14	14
Average Recovery (%)	60.0	72.0	89.4	32.9	42.2	53.2
Standard Deviation	6.7	8.9	14.4	2.6	8.5	14.8

[a]Nine sampling positions were used on each trial.

Table 8. Summary of Fly-by Tower Results for C679.

TRIAL	Q, AMOUNT OF PURE AGENT DISSEMINATED (gm/m)	R, AMOUNT OF AGENT RECOVERED (gm)	(R/Q) 100, DISSEMINATION EFFICIENCY (%)
A-1R	22.79	16.90	74.13
A-3	44.04	110.82 25.36[a]	251.61 57.58[a]
B-1	40.33	49.98	123.95
B-3	38.46	4.93	12.82

[a]These data were obtained from snoot samplers.

A complete analysis is given in Appendix I. The results obtained indicate that the type of droplet-aerosol cloud generated on these trials fails to meet the restriction inherent in the standard vertical recovery calculation procedure. Snoot and impinger samplers were positioned in pairs at each level on the tower for each trial to compare wind tunnel and field test results. Adequate data, for comparative purposes, were obtained from the snoot samplers on only one trial. The recovery results obtained on Trial A-3 with snoots are listed in Table 8. Dosage data for each sampling level on Trial A-3 are contained in Appendix I.

(2) Vertical Cloud Profile. The sampling data obtained from the tower on Trials A-1R, A-3, B-1 and B-3 define the dosage profile of the agent cloud during passage. The vertical height of the cloud and dosage variations with respect to height are also defined. The dosage values for each sampling station are presented in Appendix I.

(3) Deposition Samplers. The results obtained from deposition samplers were as follows:

(a) Horizontal Sampling. On each of the Phase B trials, a deposition sampler was placed 1.5 meters above the ground at each of the stations comprising the horizontal sampling array. Agent fallout was collected by these samplers on each trial. The results obtained are given in Appendix I.

(b) Upwind Sampling. Three rows of seven deposition samplers each were positioned on the ground upwind of the tower on each trial to detect gross agent fallout prior to the passage of the cloud

through the tower. The center row of samplers was located perpendicular to the flight line and the tower. The remaining two rows were positioned parallel to the center row and offset 30 meters left and right. The interval between samplers on each row was 15 meters. Data were obtained on six of the nine trials. Significant agent fallout was observed. On Trials A-1 and A-2, no data were obtained because the low source strength and high wind speeds produced contamination levels below the sensitivity of the chemical analysis. On Trial A-3, no samplers were used because of operational difficulties. The data obtained, given in mg/m^2, are contained in Table 20, Appendix I.

(c) Tower Sampling. The use of deposition samplers on the tower was not originally planned. It was considered desirable as a qualitative tool after the low source strength experienced on Trials A-1 and A-2. The deposition samplers located on the tower indicated that agent fallout was evident as the aerosol cloud passed through the tower. The data given in mg/m^2 for each station collecting agent fallout on Trials A-2R, A-3, B-2 and B-3 are presented in Table 21, Appendix I.

(4) Particle Size Sampling. No data were obtained from the cascade impactor samplers on this test.

(5) Area Coverage. The areas covered by dosages greater than or equal to 5 and 10 mg min/m^3 during each trial of Phase B are given in Table 9. The dosage data obtained at each sampling station are presented in Appendix I.

(6) Swab Sampling. Swab samples were taken after the completion of several missions. The results of the chemical analysis indicated that little or no contamination occurred.

Table 9. Summary of Area Coverage Results for C679.

TRIAL	AVERAGE 2-METER WIND SPEED[a] (mph)	STABILITY (F°)	AREA COVERAGE (Hectares)[b] FOR THE INDICATED DOSAGE LEVELS (mg min/m^3)			
		0.5 to 4m	≥30	≥20	≥10	≥5
B-1	8.4	-2.1	1	7	26	46
B-2	6.5	-0.5	3	5	39	62
B-3	5.3	INOP[c]	0	4	17	55

[a]These values are ascertained from the mean virtual wind track.
[b]1×10^4 m^2 = 1 hectare.
[c]Inoperative.

SECTION 3. APPENDICES

APPENDIX I. TEST DATA

1. TOWER AGENT RECOVERY

The agent recovered from the cloud passing through a single vertical sampling tower was used to provide an estimate of weapon efficiency. This estimate is the ratio of agent recovered (in grams) per meter width of cloud volume to the average quantity of agent dispersed per meter length of emission line. The agent collected on the tower was converted to a total recovery estimate using the following computation:

$$R = V \sum_{i=1}^{n} \overline{u}_i \; D_i \; \csc \theta_i$$

where:

R = Agent recovery in grams per meter width of the passing cloud

V = Uniform vertical distance, in meters, between sampling stations on the tower

n = Number of sampling stations collecting dosage

$\overline{u}_i$ = Average wind speed, in meters per minute, at the i^{th} sampling station ascertained from a detailed analysis of the meteorological data

D_i = Dosage in mg min/m^3 collected at the i^{th} sampling station

θ_i = Angle of intersection formed by the line of flight and the wind direction with respect to the tower

csc = Trigometric function used to adjust the dosages collected on the tower to emanate from an agent cloud traversing a path perpendicular to the emission line.

The estimate provided by the above computation is dependent on the following unavoidable assumptions:

a. The rates of diffusion are equal and self-cancelling along the entire length of the emission line.

b. The dissemination rate is constant; that is, crosswind homogeneity in recovery exists.

c. The vertical extent of the cloud is contained by the tower.

d. The dissemination line is of sufficient length to preclude edge effects at the tower.

e. The wind speed is constant at the i^{th} sampling level during the passage of the cloud through the tower.

On this test, assumptions "c" and "d" appeared valid. The remaining three were open to question. Results from deposition samplers showed definite fallout of large droplets. Assumption "a" ignores losses from such fallout. Surges were clearly apparent from the movies of the tests; thus, assumption "b" does not apply. The wind fluctuated during the passage of the cloud through the tower on at least two of the trials used in the analysis, rendering assumption "e" suspect. At best, the computational technique used provided results of a qualitative nature. It is not recommended that the vertical grid recoveries obtained be used as an indicator of weapon efficiency.

Table 10. Agent Recovery Data (Impinger) for C679, Trial A-1R.

SAMPLING STATION ABOVE GROUND (m)	DOSAGE AT INDICATED SAMPLING STATION (mg min/m^3)	WIND		ANGLE θ[a]		AGENT RECOVERY[b]	
		Speed (mph)	Direction (degrees)	Degrees	Cosecant	Grams	Percent[c]
1	2.5	5.50	214° 0'	64° 0'	1.1126	0.821	3.60
3	4.2	5.67	213° 0'	63° 0'	1.1223	1.434	6.29
5	3.2	6.20	211° 30'	61° 30'	1.1379	1.211	5.31
7	2.3	6.60	210° 45'	60° 45'	1.1461	0.933	4.09
9	3.2	6.80	210° 0'	60° 0'	1.1547	1.348	5.91
11	2.5	7.10	209° 30'	59° 30'	1.1606	1.105	4.85
13	1.7	7.23	209° 0'	59° 0'	1.1666	0.769	3.37
15	0.8	7.40	208° 45'	58° 45'	1.1697	0.371	1.63
17	1.3	7.40	207° 15'	57° 15'	1.1890	0.614	2.69
19	2.3	7.30	205° 0'	55° 0'	1.2208	1.100	4.83
21	1.3	7.20	203° 0'	53° 0'	1.2521	0.629	2.76
23	0.5	7.17	201° 0'	51° 0'	1.2868	0.247	1.08
25	3.2	7.10	199° 30'	49° 30'	1.3151	1.603	7.03
27	2.5	7.05	198° 0'	48° 0'	1.3456	1.272	5.58
29	2.8	7.00	196° 30'	46° 30'	1.3786	1.450	6.36
31	1.3	6.95	195° 0'	45° 0'	1.4142	0.685	3.01
33	1.3	7.00	195° 30'	45° 30'	1.4020	0.684	3.00
35	1.2	7.10	197° 30'	47° 30'	1.3563	0.620	2.72
TOTAL						16.896	74.130

[a]Angle of intersection of flight line and wind direction with respect to tower.

[b]Agent recovery per 1-meter horizontal and 2-meter vertical fields of influence.

[c]Percent grams of pure agent disseminated per meter length of emission line.

Table 11. Agent Recovery Data (Impinger and Snoot) for C679, Trial A-3.

SAMPLER	SAMPLING STATION ABOVE GROUND (m)	DOSAGE AT INDICATED SAMPLING STATION (mg min/m^3)	WIND		ANGLE θ[a]		AGENT RECOVERY[b]	
			Speed (mph)	Direction (degrees)	Degrees	Cosecant	Grams	Percent[c]
Impinger	31	7.3	17.10	324° 13'	69° 13'	1.0696	7.163	16.26
	33	8.3	17.40	323° 54'	68° 54'	1.0719	8.304	18.85
	35	13.5	17.75	322° 48'	67° 48'	1.0801	13.884	31.52
	37	10.0	18.10	321° 48'	66° 48'	1.0880	10.564	23.98
	39	15.3	18.50	320° 48'	65° 48'	1.0963	16.646	37.79
	41	19.0	18.75	319° 54'	64° 54'	1.1043	21.104	47.92
	43	17.8	19.20	319° 0'	64° 0'	1.1126	20.398	46.31
	45	4.8	19.50	318° 12'	63° 12'	1.1203	5.625	12.77
	47	3.0	19.75	317° 24'	62° 24'	1.1284	3.587	8.14
	49	1.7	19.70	317° 12'	62° 12'	1.1305	2.031	4.61
	51	1.3	19.30	317° 24'	62° 24'	1.1284	1.519	3.45
	TOTAL						110.825	251.62
Snoot	31	0.5	17.10	324° 13'	69° 13'	1.0696	0.491	1.11
	33	2.5	17.40	323° 54'	68° 54'	1.0719	2.501	5.68
	35	2.2	17.75	322° 48'	67° 48'	1.0801	2.263	5.14
	37	3.7	18.10	321° 48'	66° 48'	1.0880	3.909	8.88
	39	4.7	18.50	320° 48'	65° 48'	1.0963	5.114	11.61
	41	2.6	18.75	319° 54'	64° 54'	1.1043	2.888	6.56
	43	4.2	19.20	319° 0'	64° 0'	1.1126	4.813	10.93
	45	2.4	19.50	318° 12'	63° 12'	1.1203	2.813	6.39
	47	0.5	19.75	317° 24'	62° 24'	1.1284	0.598	1.36
	49	0.0	19.70	317° 12'	62° 12'	1.1305	0.000	0.00
	51	0.0	19.30	317° 24'	62° 24'	1.1284	0.000	0.00
	TOTAL						25.390	57.65

[a] See Table 10.
[b] See Table 10.
[c] See Table 10.

Table 12. Agent Recovery Data (Impinger) for C679, Trial B-1.

SAMPLING STATION ABOVE GROUND (m)	DOSAGE AT INDICATED SAMPLING STATION (mg min/m^3)	WIND		ANGLE θ[a]		AGENT RECOVERY[b]	
		Speed (mph)	Direction (degrees)	Degrees	Cosecant	Grams	Percent[c]
9	1.5	9.80	313° 33'	71° 33'	1.0542	0.831	2.06
15	1.2	10.75	313° 4'	71° 4'	1.0572	0.732	1.82
19	1.5	11.10	311° 9'	69° 9'	1.0701	0.956	2.37
21	4.0	11.30	310° 6'	68° 6'	1.0778	2.613	6.48
23	3.3	11.40	309° 6'	67° 6'	1.0856	2.191	5.43
25	9.2	11.60	308° 12'	66° 12'	1.0929	6.257	15.52
27	7.3	11.70	307° 24'	65° 24'	1.0998	5.039	12.50
29	11.7	11.80	306° 33'	64° 33'	1.1075	8.202	20.34
31	8.5	11.90	305° 51'	63° 51'	1.1140	6.045	14.99
33	9.3	12.05	305° 6'	63° 6'	1.1213	6.741	16.72
35	4.0	12.15	304° 24'	62° 24'	1.1284	2.942	7.30
37	2.3	12.25	303° 42'	61° 42'	1.1357	1.717	4.26
39	1.2	12.30	303° 0'	61° 0'	1.1434	0.905	2.24
41	1.5	12.40	302° 24'	60° 24'	1.1501	1.148	2.85
43	1.7	12.50	301° 51'	59° 51'	1.1565	1.318	3.27
55	3.3	11.75	304° 27'	62° 27'	1.1279	2.346	5.82
TOTAL						49.983	123.947

[a]See Table 10.
[b]See Table 10.
[c]See Table 10.

Table 13. Agent Recovery Data (Impinger) for C679, Trial B-3.

SAMPLING STATION ABOVE GROUND (m)	DOSAGE AT INDICATED SAMPLING STATION (mg min/m^3)	WIND		ANGLE θ[a]		AGENT RECOVERY[b]	
		Speed (mph)	Direction (degrees)	Degrees	Cosecant	Grams	Percent[c]
1	0.85	1.45	317° 24'	91° 24'	1.0004	0.066	0.17
3	1.14	3.42	323° 30'	97° 30'	1.0086	0.211	0.55
5	1.70	3.45	326° 30'	100° 30'	1.0170	0.320	0.83
7	2.31	3.25	328° 0'	102° 0'	1.0263	0.412	1.07
9	2.84	3.30	329° 30'	103° 30'	1.0284	0.517	1.34
11	2.00	3.60	330° 30'	104° 30'	1.0329	0.399	1.04
13	1.70	3.85	331° 30'	105° 30'	1.0377	0.364	0.95
15	2.84	4.10	332° 0'	106° 0'	1.0457	0.653	1.70
17	2.56	4.20	334° 30'	108° 30'	1.0545	0.608	1.58
19	1.14	4.30	338° 0'	112° 0'	1.0864	0.286	0.74
21	1.14	4.35	342° 0'	116° 0'	1.1223	0.299	0.78
23	1.14	4.40	345° 0'	119° 0'	1.1547	0.311	0.81
25	0.85	4.44	347° 30'	121° 30'	1.1728	0.237	0.62
27	0.85	4.48	350° 0'	124° 0'	1.2208	0.249	0.65
TOTAL						4.9320	12.823

[a]See Table 10.
[b]See Table 10.
[c]See Table 10.

APPENDIX

XI

RDTE PROJECT NO. 1B025001A128
USATECOM PROJECT NO. 5-5-9955-22
DTC PROJECT NO. B502

DOWNWIND DIFFUSION
FROM AERIAL LINE SOURCE RELEASES
AT DUGWAY PROVING GROUND

SUMMARY REPORT

BY

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FEBRUARY 1970

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DETAILS OF TEST

INTRODUCTION

Data obtained from the B502 program provided some of the most complete information to date on the movement of particulate aerosols generated from a line source. The program consisted of two phases - A and B. Phase B was an expansion of the Phase A objective. Details and results of both phases will be grouped together for convenience of discussion.

OBJECTIVES

Refer to paragraph 1.4.

METHOD

Test Grid

The test program was conducted on the Aerial Spray Grid (ASG) at Dugway Proving Ground. The grid, consisting of two arrays of three radial sampling lines each, is presented in Figure 1. The south array was utilized for northerly wind flows, and the north array for southerly wind flows. Samples were taken on this grid to 24 kilometers (15 miles) downwind from the release line. For the Phase B trials, aerosol samples were taken only on the center radial.

Dissemination

The aerial FP releases were performed by a Model D dry particulate disseminator, the aerial BG releases by an Aero 14B spray tank, and the ground-level FP releases by a Mark IV Skil-blower aerosol generator. All releases were performed along the dissemination line indicated in Figure 1. The aerial FP releases were made from an O-1A, a U-6A, or a JU-8D aircraft. The aircraft for each trial are listed in table 1. All BG releases were made from an A-4 aircraft. The ground level FP releases were from two trucks driven simultaneously in opposite directions from the center of the indicated flight line. Several of the trials involved a double release. The ground-level FP releases were performed simultaneously with aerial releases, starting at the vertex of the grid array the moment the aerial disseminator passed directly over that vertex.

Sampling Technique

Sampling for Total Surface Dosages. Surface dosages were sampled to a distance of 24 kilometers (15 miles) downwind on the grid array by membrane filter samplers, placed on the grid arrays as pictured in Figure 1. Only the center radials (radials 18) were

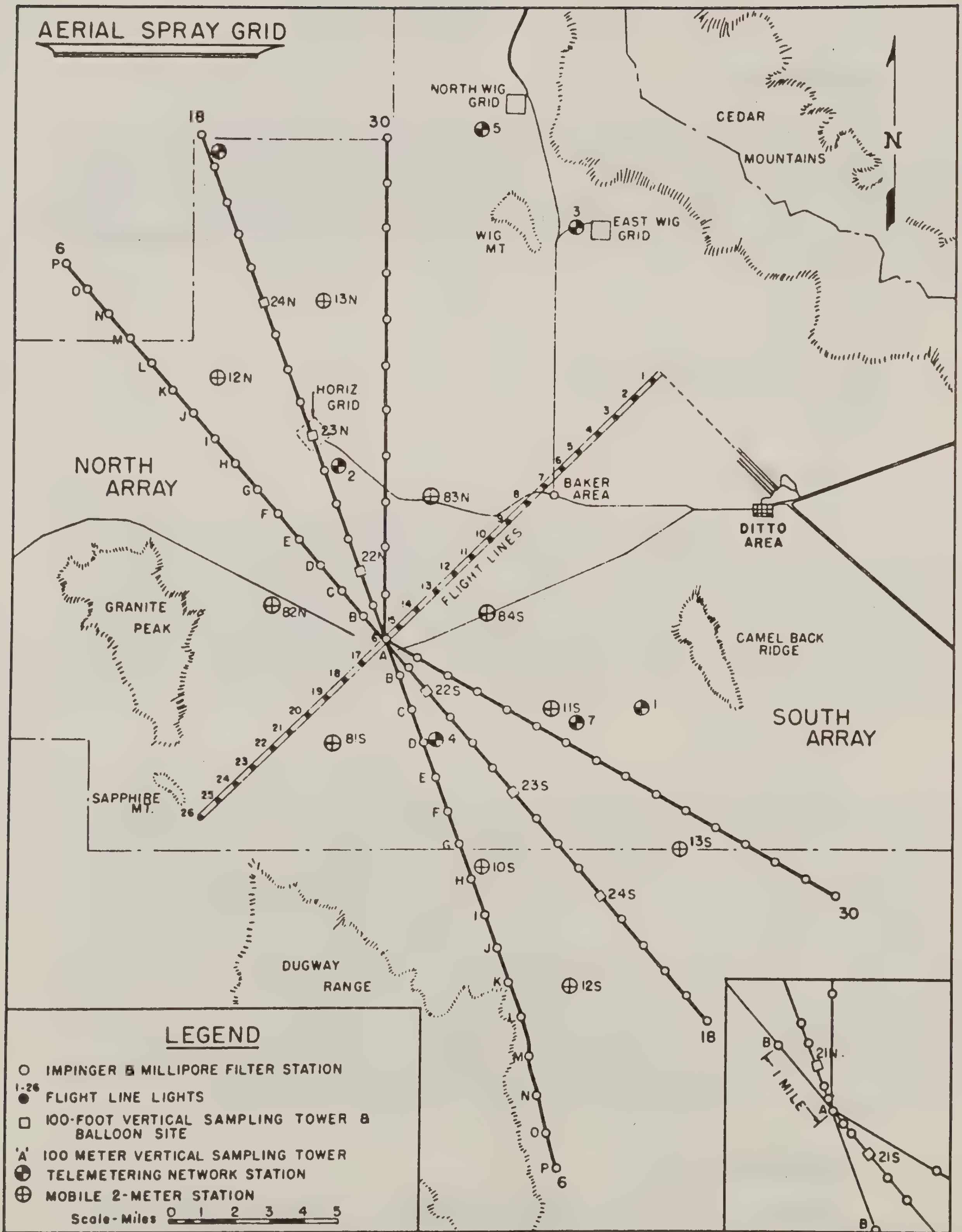

Figure 1. Test Grid for B502.

Table 1. General Information for Each Trial, B502.

TRIAL PHASE AND NUMBER[a]	DATE OF TRIAL	TIME OF TRIAL (MST)	TYPE OF DISSEMINATOR	MATERIAL DISSEMINATED	RELEASE HEIGHT (meters)	EFFECTIVE SOURCE STRENGTH OBTAINED
A1	25 Oct 60	2105 2101	Model D-1 in O-1A Aero 14B in A-4	Yellow FP BG	139 139	0.702[b]
A2	26 Oct 60	2358 2355	Model D-1 in O-1A Aero 14B in A-4	Yellow FP BG	152 119	0.988
A3	31 Oct 60	2245 2241	Model D-1 in O-1A Aero 14B in A-4	Yellow FP BG	61 49	0.801
A4	15 Nov 60	2128 2124	Model D-1 in O-1A Aero 14B in A-4	Yellow FP BG	122 107	0.850
A5	17 Nov 60	1925 1922	Model D-1 in O-1A Aero 14B in A-4	Yellow FP BG	49 73	0.860
A6	28 Nov 60	2056 2052	Model D-1 in O-1A Aero 14B in A-4	Yellow FP BG	69 70	0.824
B1	14 Mar 61	2219	Model D-1 in U-8D	Yellow FP	76	0.63×10^{10}[c]
B2	15 Mar 61	1900	Model D-1 in U-8D	Yellow FP	139	0.71×10^{10}
B3	22 Mar 61	2306	Model D-1 in U-8D	Yellow FP	35	0.65×10^{10}
B4	28 Mar 61	2329	Model D-1 in U-8D	Yellow FP	78	0.68×10^{10}
B5	29 Mar 61	2009	Model D-1 in U-8D	Yellow FP	38	0.68×10^{10}
B6	5 Sep 61	2056	Model D-1 in U-8D Model D-1 in U-6A	Yellow FP Green FP	76 122	0.71×10^{10} 1.14×10^{10}

(Continued)

[a]See footnote at end of table, page 12.

Table 1. General Information for Each Trial, B502. (Continued)

TRIAL PHASE AND NUMBER[a]	DATE OF TRIAL	TIME OF TRIAL (MST)	TYPE OF DISSEMINATOR	MATERIAL DISSEMINATED	RELEASE HEIGHT (meters)	EFFECTIVE SOURCE STRENGTH OBTAINED
B7	4 Oct 61	1630	Model D-1 in U-8D Model D-1 in U-6A	Yellow FP Green FP	69 122	0.68×10^{10} 1.20×10^{10}
B8	19 Oct 61	1629	Skil-blower in Truck Model D-1 in U-6A	Yellow FP Green FP	2 122	0.08×10^{10} 1.36×10^{10}
B9	6 Jun 62	1849	Model D-1 in U-8D Model D-1 in U-6A	Yellow FP Green FP	76 131	0.79×10^{10}
B10	7 Jun 62	1733	Model D-1 in U-8D Model D-1 in U-6A	Yellow FP Green FP	69 126	0.71×10^{10} 1.47×10^{10}
B11	12 Jun 62	1951	Model D-1 in U-8D Model D-1 in U-6A	Yellow FP Green FP	27 136	0.65×10^{10} 1.25×10^{10}
B12	21 Jun 63	2050	Model D-1 in U-8D Model D-1 in U-6A	Yellow FP Green FP	76 122	0.54×10^{10} Malfunction
B13	20 Jan 64	2003	Model D-1 in U-8D	Yellow FP	30	0.74×10^{10}
B14	18 Mar 64	1702	Model D-1 in U-8D	Yellow FP	122	0.74×10^{10}
BA1	8 Jun 65	2329	Skil-blower in Truck Model D-1 in U-6A	Yellow FP Green FP	2 56	0.24×10^{10} 1.25×10^{10}
BA2	28 Jun 66	2157	Skil-blower in Truck Model D-1 in U-8D	Yellow FP Green FP	2 90	0.22×10^{10} 1.55×10^{10}

(Concluded)

[a]A designates Phase A trials, B designates Phase B trials, and BA designates supplemental Phase B trials.

[b]All Phase A results are in terms of grams per minute.

[c]All Phase B results are in terms of particles per meter.

utilized for the Phase B trials. Each sampler was placed 1.5 meters (5 feet) above the ground, and was aspirated at a rate of six liters per minute for a sufficient length of time to assure complete passage of the aerosol cloud. For trials involving BG, AGI in series with pre-impingers were placed in the same positions as the membrane filters.

2.3.3.2 Sequential Sampling. To confirm total dosage collection and to accurately determine actual time of aerosol presence at a particular position, samples were taken by sequential samplers operated simultaneously with the surface dosage samplers. Andersen samplers connected to a Windsoc sequentializer were used in Phase A; in Phase B, membrane filter samplers were connected to the sequentializers. Sequential sampling was performed in Phase A at the 8.0-, 16.1-, and 24.1-kilometer (5-, 10-, and 15-mile) positions on radials 6 and 18, and 4.8-, 11.3-, and 17.7 kilometer (3-, 7-, and 11-mile) positions on radial 30. Sequential sampling was performed at the 3.2-, 6.4-, 9.7-, 12.9-, and 16.1-kilometer (2-, 4-, 6-, 8-, and 10-mile) positions on radial 18 during Phase B. Only BG was sampled in Phase A and only FP was sampled in Phase B.

2.3.3.3 Tower Sampling. Details of sampler placement are found in references 6, 9, 10, 11, of Appendix III. Membrane filter samplers were placed at specified intervals, on the 100-meter tower (ASG Tower) at the vertex of the sampling array, and at specified intervals on 30-meter towers located at the 0.8-, 3.2-, 9.7-, and 16.1-kilometer[1] 0.5-, 2-, 6-, and 10-mile) positions on the center radial. For trials involving collection of BG, AGI's in series with pre-impingers were placed at the same sampling positions as the membrane filter samplers. In Phase B, model 60-A rotorod samplers were placed at the top three sampling position on each of the downwind towers in order to provide membrane filter - rotorod sampling comparisons.

2.3.3.4 Balloon-Supported Sampling. Tethered balloons were placed at each of the downwind tower positions. Two hundred and forty-four meters (800 feet) of cable was used to tether each balloon.[2] Model 60-A rotorod samplers were placed at specified intervals on each cable to provide aerosol sampling above the height of the towers. Exact details of trial-to-trial placement of each sampler are found in references 6, 9, 10, and 11 of Appendix III. The sampling heights for the earlier trials were considered to be the distance from the lower end of the cable to the samplers. A clinometer was used to

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[1]The 30-meter tower located at the 16.1-kilometer postion was utilized only in Phase B.

[2]In the two supplemental Phase B trials, 305 meters (1,000 feet) of cable were used.

determine the actual height of the samplers in the latter trials.

2.3.4 Meteorological Coverage

An extensive discussion of the instrumentation used on the ASG array to record the effects of the meteorological parameters of interest is found in references 6, 9, and 11 of Appendix III. The locations of the meteorological stations at which data were obtained are shown in Figure 1. To provide a more complete study of the meso-scale meteorological environment, pibal information was obtained and aircraft temperature soundings were made to an altitude of 335 meters (1,100 feet). Of special interest were the instruments used to record vertical wind fluctuations. In Phase A and in the first eight Phase B trials, the fluctuations were recorded on an Esterline-Angus (EA) chart, using standard Beckman and Whitley wind vanes mounted with the masts horizontal, oriented so that all vane rotation was in a south-east-northwest plane. The remaining Phase B trials were completed with Gelman bivanes.

2.4 RESULTS

2.4.1 Meteorological Results

The B502 trials have been classified in four categories of meteorological stability conditions (reference 4, Appendix III), and are summarized in Table 2. Briefly these four categories are: (1) Releases in a stable layer above an inversion cap; (2) Releases in a stable layer below an inversion cap, above and below 50 meters and at surface; (3) Releases in a near-neutral layer with no inversion, above and below 90 meters; and (4) Releases made in light winds.

Table 2 shows values of meteorological parameters (wind speed, temperature gradient, and cloud cover) characterizing the environment during aerosol travel. Detailed studies of the meteorological environment are described in references 6, 7, 9, 10, and 11 of Appendix III. Descriptions of synoptic conditions influencing each trial are contained in Appendix I.

2.4.2 Source Strength

Effective source strengths were determined for each release (see references 6, 7, 9, 10, and 11 of Appendix III), and are listed in Table 1. FP releases in Phase A are expressed in grams. Green FP release results in Phase B were extrapolated from the Phase B yellow FP results. Quantities needed to determine source strength (munition efficiency, lot particle density, etc.) were precisely determined for the four supplementary Phase B releases; figures showing the effective source strength of these trials are therefore more exact.

Table 2. Description of Meteorological Environment for Each Successful Trial, B502.

METEOROLOGICAL CATEGORY AND TRIAL[a]	RELEASE HEIGHT (meters)	MEAN WINDSPEED[b] (m/s)	TEMPERATURE GRADIENT[b] (F°) 0.5m - 15m	TEMPERATURE GRADIENT[b] (F°) 0.5m - 100m	CLOUD COVER (10ths)
Release Above Inversion Cap					
B6 - Yellow	76	9.4	7.5	13.1	1
B6 - Green	122	9.4	7.5	13.1	1
A4	122	10.3[c]	0.4	-	0
A1	136	3.1[c]	12.0	17.0	0
B11 - Green	136	5.2	6.8	10.2	7
Releases Under Inversion Cap Above 50 Meters					
A5	49	4.5[c]	11.0	17.0	0
A3	61	2.2[c]	>11.0	>15.0	1
A6	69	3.4[c]	11.0	15.0	0
B1	76	8.8	3.2	6.0	4
B4	78	9.5	5.6	11.0	5
BA2 - Yellow	91	8.0[c]	3.4	12.3	1
B8 - Green	122	5.8			6
Releases Under Inversion Cap Below 50 Meters					
B11 - Yellow	27	5.2	6.8	10.2	7
B13	30	8.6	2.5	3.6	9
B3	35	6.0	5.6	10.5	8
Releases Under Inversion Cap at Surface					
B8 - Yellow	0	5.7	2.4	1.0	6
BA2 - Yellow	0	8.0[c]	3.4	12.3	1

(Continued)

[a] See footnote at end of table, page 16.

Table 2. Continued

METEOROLOGICAL CATEGORY AND TRIAL[a]	RELEASE HEIGHT (meters)	MEAN WINDSPEED[b] (m/s)	TEMPERATURE GRADIENT[b] 0.5m - 15m	TEMPERATURE GRADIENT[b] 0.5m - 110m	CLOUD COVER (10ths)
Releases in Neutral Conditions Above 90 Meters					
B14	122	9.4	-2.0	-4.3	5
B10 - Green	126	4.5	-2.5	-0.6	0
B9 - Green	131	3.8	0.1	-1.3	2
B2	139	8.7	0.6	-0.6	10
A2	152	8.0[c]	0.7	0.4	4
Releases in Neutral Conditions Under 90 Meters					
B5	38	10.5	0.2	0.0	9
B10 - Yellow	69	4.5	-2.5	-0.6	0
B9 - Yellow	76	3.8	0.1	-1.3	2
B12	76	4.3	0.0	0.0	0
Releases in Unstable Conditions					
BA1 - Yellow	0	4.2[c]	3.6	9.5	10
BA1 - Green	56	4.2[c]	3.6	9.5	10
B7 - Yellow	69	1.7	1.1	-2.88	0
B7 - Green	122	1.7	1.1	-2.8	0

(Concluded)

[a]The trials are listed within a category in order of their ascending releases heights.

[b]These values are taken from references 6, 10, and 11 of Appendix III.

[c]The average for the 48-meter level was used as a mean estimate in these trials.

Table 3. Summary of Ground Level Results Obtained in B502, Phases A and B.

METEOROLOGICAL CATEGORY AND TRIAL[a]	DISSEMINATION HEIGHT (m)	DISTANCE FROM RELEASE TO GROUND LEVEL			RELATIVE MAGNITUDE OF SURFACE RECOVERIES
		Initial Recovery (km)	Largest Recovery (km)	Farthest Recovery (km)	
Release Above Inversion Cap					
B6 - Yellow	76	8.0	17.7	>22.5	Low
B6 - Green	122	None	None	None	None
A4	122	14.5	14.5	>24.1	Low
A1	136	None	None	None	None
B11 - Green	136	12.9	14.5[b]	14.5	Low
Releases Under Inversion Cap Above 50 Meters					
A5	49	4.8	20.9	>24.1	Medium
A3	61	8.0	22.5	>24.1	Medium
A6	69	4.8	12.9	>24.1	Medium-Low
B1	76	0.8	9.7	>24.1	Low
B4	78	4.8	6.4	16.1	Low-Medium
BA2 - Green	91	11.2	14.5	22.5	Low
B8 - Green	122	4.8	8.0	19.3	Medium
Releases Under Inversion Cap Below 50 Meters					
B11 - Yellow	27	<0.1	<0.1	14.5	High
B13	30	<0.4	6.4	>24.1	Medium
B3	35	1.6	6.4	>24.1	Medium-High
Releases Under Inversion Cap At Surface					
B8 - Yellow	0	<0.4	0.8	16.1[b]	Low-Medium[c]
BA2 - Yellow	0	<0.1	<0.4	14.5	Medium[c]

(Continued)

[a]See footnote at end of table, page 19.

Table 3. Continued

METEOROLOGICAL CATEGORY AND TRIAL[a]	DISSEMINATION HEIGHT (m)	DISTANCE FROM RELEASE TO GROUND LEVEL			RELATIVE MAGNITUDE OF SURFACE RECOVERIES
		Initial Recovery (km)	Largest Recovery (km)	Farthest Recovery (km)	
Releases in Neutral Conditions Above 90 Meters					
B14	122	1.6	16.1	19.3	Low
B10 - Green	126	<0.4	<0.4	4.8[b]	Low-Medium
B9 - Green	131	3.2	3.2	6.4[b]	Low-Medium
B2	139	3.2	3.2	4.8[b]	Low
A2	152	6.4	6.4	>24.1	Low
Releases in Neutral Conditions Under 90 Meters					
B5	38	<0.4	1.2	>24.1	Medium
B10 - Yellow	69	<0.4	<0.4	4.8[b]	Low-Medium
B9 - Yellow	76	1.6	6.4	6.4[b]	Medium-Low
B12	76	0.8	1.2	9.7[b]	Low-Medium
Releases in Unstable Conditions					
BA1 - Yellow	0	<0.1	1.6	11.3[b]	Low-Medium
BA1 - Green	56	1.2	9.7	22.5[b]	High
B7 - Yellow	69	<0.4	<0.4	19.3	Medium
B7 - Green	122	<0.4	9.7	20.9[b]	Medium

(Concluded)

[a]Trials were ordered within categories with increasing release altitude.

[b]Value influenced by edge effects.

[c]Source strengths were low and not comparable to the aerial releases.

2.4.3 Surface Recoveries

The recovery data were inspected to determine at which downwind position the aerosol first touched the ground, at which ground-level position the largest recovery was made, and at which ground-level position the most distant downwind recovery was made. The results are given in Table 3. In many of the trials, the aerosol was transported to the side of the grid array before it reached the last sampler or became diffused to the point of extinction. In these cases, the recoveries are described as influenced by edge (of aerosol cloud) effects.

2.4.4 Vertical Distribution of Recoveries

Recoveries from Phase B releases were converted to dosages per unit of effective source strength, plotted on a vertical cross section of the sampling lines, and equal dosage contours were constructed about them. These contours provided profiles of the downwind movements of the aerosol cloud and delineated the upper and lower extent of the cloud at various positions. Similar contours were constructed around the actual recoveries for Phase A. Information was not available on particulate density (particles per gram) of FP material released in Phase A. This prevented conversion of recoveries to dosage per unit of effective source strength in the Phase A trials. Although samples taken prior to conducting many of the trials indicated presence of background FP, this presented no major difficulty in data analysis. The level was within the error of sampling, hence was ignored. Determinations of the cloud extent were made from dosages considered to be high enough to avoid recoveries due strictly to this background. The plots and contours of each trial can be found in references 6, 9, 10, and 11 of Appendix II. The upper and lower extent of the cloud at four positions is indicated for all releases in Table 4.

2.4.5 BG-FP Comparisons

Maps comparing ground-level FP and BG recoveries in the same trial and profiles of vertical recoveries comparing FP with BG recoveries in the same trial are shown in reference 7 of Appendix III. A quantitative comparison of FP and BG recoveries was made in this reference. Only a limited number of comparisons was possible because of the many small recoveries and lack of adequate source strength estimates. No real differences were indicated by a simple sign test of differences.

2.5 ANALYSIS

2.5.1 Aerosol Cloud Trajectories

In order to determine how far downwind the aerosol cloud continued to remain within the grid array and if enfilading (transportation of the cloud along the crosswind axis) occurred, trajectories of cloud travel were calculated. Only rough estimates of the trajectories

Table 4. Vertical Cloud Extent at Four Downwind Locations, Phases A and B, B502.

METEOROLOGICAL CATEGORY AND TRIAL [a]	DISSEMINATION HEIGHT	CLOUD EXTENT AT 0.8 KM DOWNWIND		CLOUD EXTENT AT 3.2 KM DOWNWIND		CLOUD EXTENT AT 9.7 KM DOWNWIND		CLOUD EXTENT AT 16.1 KM DOWNWIND	
	(m)	Upper (m)	Lower (m)	Upper (m)	Lower (m)	Upper (m)	Lower (m)	Upper (m)	Lower (m)
Releases Above Inversion Cap									
B6 - Yellow	76	104	43	76	23	128	0	145	0
B6 - Green	122	122	84	130	91	183	114	190	122
A4	122	206	130	244	53	NS[b]	53	ND[e]	ND
A1	136	206	91	NS	53	NS	130	ND	ND
B11 - Green	136	NS	61	NS	8	30[d]	21[d]	_[d]	-
Released Under Inversion Cap Above 50 Meters									
A5	49	91	20	91	20	130	0	ND	ND
A3	61	NS	24	244	6	NS	0	ND	ND
A6	69	91	24	130	11	91	0	ND	0
B1	76	NS	0	NS	0	160	0	49	0
B4	78	76	37	134	3	152	0	137	0
BA2 = Green	91	80	33	100	30	105	10	160	5
B8 - Green	122	171	91	152	53	NS	0	88	0
Releases Under Inversion Cap Below 50 Meters									
B11 = Yellow	27	49	0	NS	0	46	0	190	0
B13	30	101	0	145	0	130	0	130	0
B3	35	37	8	46	0	61	0	88	0
Releases Under Inversion Cap At Surface									
B8- Yellow	0	49	0	76	0	158	0	NS	0
BA2 - Yellow	0	35	0	70	0	90	0	140	5

[a]See footnote at end of table, page 21.

(Continued)

Table 4. Continued

METEOROLOGICAL CATEGORY AND TRIALS[a]	DISSEMINATION HEIGHT	CLOUD EXTENT AT 0.8 KM DOWNWIND		CLOUD EXTENT AT 3.2 KM DOWNWIND		CLOUD EXTENT AT 9.7 KM DOWNWIND		CLOUD EXTENT AT 16.1 KM DOWNWIND	
	(m)	Upper (m)	Lower (m)	Upper (m)	Lower (m)	Upper (m)	Lower (m)	Upper (m)	Lower (m)
Releases in Neutral Conditions Above 90 Meters									
B14	122	168	53	NS	0	NR[e]	0	NR	0
B10 - Green	126	107	0	175	0	76	18	-	-
B9 - Green	131	244	53	NS	0	-	-	-	-
B2	139	210	69	NR	0	-	-	-	-
A2	152	NR	NR	NR	0	NR	0	-	-
Releases in Neutral Conditions Under 90 Meters									
B5	38	79	0	122	0	98	0	NR	0
B10 - Yellow	68	154	0	183	0	46	23	-	-
B9 - Yellow	76	168	30	NS	0	-	-	-	-
B12	76	223	37	NS	0	43	-	-	-
Releases in Unstable Conditions									
BA1 - Yellow	0	90	0	110	0	50	0	-	-
BA1 - Green	56	120	0	230	0	120	0	NS	0
B7 - Yellow	69	NS	0	NS	0	NS	0	152	0
B7 - Green	122	NS	0	NS	0	NS	0	145	0

(Concluded)

[a]Trials were ordered within categories with increasing release altitude.

[b]Not Sampled - It implies that the upper extent exceeded the topmost sampling level (180 - 250 meters).

[c]No Data.

[d]Value influenced by edge effects.

[e]No Recoveries - No sampling was performed above 30 meters in this trial.

were made in Phase A. The method used to present a map of the trajectories was to extend vectors, computed from one-hour averages of wind speed and directions, from the indicated meteorological sampling positions. These maps are presented in reference 6 of Appendix III. A more detailed trajectory analysis was performed in Phase B after the development of a better technique which involved the projection of the movement of five points on the release line. The projections were made at five-minute intervals from averages of wind speed and direction data obtained from meteorological sensors in the vicinity of the point. The averages were weighed by the relative distances of the sensors from the point. The positions of the first and last point were selected so they would roughly follow the path of the outer edge of the aerosol. These trajectories are shown in references 9 and 10. No trajectories were calculated for the supplemental trials of Phase B.

Sampling Height Correction

After a preliminary analysis of Phase A and the first few Phase B trials, it was concluded that the drift of balloons from the vertical was too large to be ignored. Clinometers were used to measure the cable angle in the remaining trials so that actual sampling heights could be estimated.

Rotorod Collection Rates

In the Phase A trials, the collection rates of the rotorods were arbitrarily assumed to be one-third that of the membrane filter samplers. In Phase B, direct comparisons were made at the top three positions of the 30-meter tower, and a median value was selected to represent the actual collection rate. This value was in good agreement with trials run specifically to determine rotorod collection efficiency. A detailed analysis of B502 rotorod efficiencies can be found in reference 9 of Appendix III.

Effective Source Strength

To apply mathematical models to data obtained from aerosol releases, an estimate of the source strength was needed. The number of aerosolized particles per gram released was not established for the FP lot used in Phase A, therefore estimated effective source strengths were expressed in terms of grams. The number of aerosolized particles per gram released was known for the yellow FP used in Phase B but was not measured directly for the green FP. Inspection of recoveries of the two colors of FP in simultaneous releases indicated that the green FP values were roughly twice that of the yellow FP values. Since the theoretical source strengths in grams were roughly equal the effective source strength of green FP used in this analysis was estimated to be twice that of yellow FP. Technology programs described in reference 11 of Appendix III, provided more precise effective source strength information on the FP lots used in the two supplemental trials.

The Unit D/Q

In order to permit valid trial-to-trial comparisons, each recovery was adjusted for source strength and collection rates. Division of the recovery by the collection rate yields a quantity, termed dosage (D). Further division by the effective source strengths (Q) of the disseminator producing the aerosol (defined as the actual source strength times the dissemination efficiency) produces the quantity (D/Q) which is independent of both source strengths and sampling rates. Plots and contours discussed in paragraph 2.4.4 were constructed from recoveries converted to D/Q units and therefore are comparable from trial to trial.

Transport Models

Most transport models are based upon a Gaussian form with differences between models due mainly to the method used to specify the rate of vertical expansion of the aerosol. Various models in current use are described in detail in reference 4, Appendix III, and a comparison of the model-predicted values (maximum dosage, and distance to maximum dosage) is made with the values obtained in each Phase B trial. The wide range of ratios of observed to calculated values pointed out the general nature of these models. Equal vertical dosage contours were determined theoretically by the use of one of these Gaussian models. Vertical eddy diffusivities were derived from estimates of the vertical flux of heat. These contours were placed on the same contour maps discussed in paragraph 2.4.4 in order to compare theoretical profiles with the actual profiles obtained (see references 9 and 10 of Appendix III). Again, the wide range of differences points out the general nature of these models.

SECTION 3. APPENDICES

APPENDIX I. SYNOPTIC DESCRIPTION

Introduction: In general, synoptic conditions on a larger scale influenced the mesoscale meteorological environment in which each trial was conducted. The term "scale" is nearly synonymous with magnitude, but with the implication of influence of motions of adjoining size. Since synoptic scale information was not presented in the body of the report, synoptic influence was not considered. This appendix attempts to provide information of additional meteorological scales influencing the test results.

Large-scale conditions in effect at test time and for a period after are listed for individual trials in the following order: date, time (MST) of beginning of test, sunset time (MST), temperature differences respectively at 0.5 meters to 45.6 meters (1.61 to 150 feet). An added temperature difference is sometimes accounted for approximately as temperature at release height-minus-2-meters temperature. Winds are indicated for similar levels.

Trial A-1, 25 October 1960, 2105 MST, 1739 MST Sunset: The planetary scale influence was consistent with the mesoscale and microscale with decoupling optimum. A wedge of high pressure extended from eastern Oregon to western Texas, as viewed on the mean sea level projection. The grid scale conditions were: wind SE 7 mph; the 1.6' to 150 temperature gradient, +12° F; 2M to 300', +17° F; the cloud cover was less than one-tenth. Release time was 2105 MST compared to 1739 MST sunset, and approximately 1700 MTS day to night change in lowest stability (1/2 to 4 meters).

Trial A-2, 26 October 1960, 2358 MST, 1738 MST Sunset: In the same order +0.7, 0.4° F, 18 mph northerly, 4/10 cloud cover, possible influence was postfrontal. During 24 hours prior to test, stable conditions prevailed. The airmass over the grid was displaced with colder air with resulting winds generally from the north and over Hill Field, Salt Lake Airport, Highway 40, and NW on the grid. The same cold front was delineated: Santa Barbara, Las Vegas, Ely and Billings at 1700 MST displayed on the MSL and 850 mb charts.

The 2358 MST release should be compared with 1738 MST sunset on a purely diurnal basis modified by the front which cleared through Dugway during the period 1700 to 1900 MST, approaching from northwest and proceeding southeast.

Trial A-3, 31 October 1960, 2245 MST, 1732 MST Sunset: +11° F, +15° F, S 5 mph, 1/10 cloud cover, inversion 280' or above, stable on all scales (or magnitudes), micro through planetary. From 1700 MST to 2300 MST, the high pressure on the MSL projection was centered over southern Utah. An upper-level ridge was directly over Dugway, with the 500 mb constant pressure chart showing WNW flow, with maximum speeds in northern Utah.

Trial A-4, 15 November 1960, 2128 MST, 1715 MST Sunset: 0.4° F, (1.6' to 150'), SE 23 mph. The large scale was moderately stable, with an inversion near 450', but the lower layer was a near-neutral case by comparison. The circulation over areas greater than grid scale was consistent with the drainage from the southeast direction. During the prior 24 hours, a new high pressure pattern replaced an older high pressure pattern. Above 8000 feet, flow was from the northwest at 15/1400 MST, but southerly flow was dominant below 8000' and after that time.

Trial A-5, 17 November 1960, 1925 MST, 1714 MST Sunset: +11° F, +17° F, ESE 10 mph, no clouds. Inversion approximates 300 feet with stable case on all scales and ESE flow. A cool high pressure was over Utah on MSL projection, with center over Grand Junction, Colorado. Dugway was in a warm sector, and the position of the pressure center was confirmed at 850 mb, and 5000' to 8000' winds from SSW becoming westerly at 14,000" MSL, conforming to a pattern further aloft. The 500 mb surface chart near 19,000 feet displayed a trough pattern along central Colorado to western North Dakota.

Trial A-6, 28 November 1960, 2056 MST, 1708 Sunset: +11° F, +15° F, 7.5 mph, no clouds. High pressure was centered in the northeast corner of Utah or southwest Wyoming, confirming a stable mesoscale. The large planetary features, decoupled, shown on the 500 mb chart were: a long ridge from San Diego to Spokane to Jasper and a trough over North Dakota and Manitoba determining NW long-wave flow.

Trial B-1, 14 March 1961, 2219 MST, 1837 MST Sunset: +4.3° F, +6.0° F, with 3.30° F at T(h)-T(2M) where h is release height, 4/10 cloud cover. This was a stable case, with MSL projection high pressure centered over Grand Junction, a warm sector over western Utah giving S to SE flow, with 1012 mb isobar in western Utah on MSL projection. The Continental Divide was the location of the nearest stationary front. A southerly flow extended over a large area from 8000 feet through the 500 mb level over Utah, becoming an anticyclic flow over Wyoming and Colorado to at least 8000'.

Trial B-2, 15 March 1961, 1900 MST, 1839 MST Sunset: +0.6° F, -0.6° F, -0.3° F, neutral, 10/10 cloud cover. Post-frontal conditions prevailed, and the frontal passage across Dugway Proving

Ground took place between 1400 and 1700 MST. All flow scales were coupled diurnally to neutral conditions. The preceding synoptic events were: front extended from the Gulf of California through eastern Nevada to Missoula and Calgary and indicated throughout several altitudes. This large-scale front progressed:

1100: Front at Wendover extended southward through the Deep Creek range, Cedar City, Williams, Gulf of California; northward, Wendover-Missoula-Calgary.

1400: Front entered western part of Dugway Proving Ground, with winds at ground confused and not all changing to southerly.

1700: Most of Dugway had experienced a complete change of air mass.

1800: Anticyclic center over Colorado was on 8000' level, SSW flow was direction over Las Vegas, becoming S over Utah.

2000: Local southerly winds were sustained in spite of the front on the MSL chart.

2300: High pressure increased over Nevada, 850 mb wave was centered over Ely and was moving toward Delta, with SSW winds aloft over the Dugway grid.

Trial B-3, 22 March 1961, 2306, 2302 MST, 1846 MST, Sunset: 5.6° F, 10.5° F, +3.6° F, stable, 8/10 cloud cover. Both MSL chart and 850 mb chart showed a low over Nevada, a high over Wyoming, and flat gradient and south flow in western Utah. The 850 mb and 500 mb south flow indicates a deep layer throughout, modified in location by altitude. The typical Nevada low was located on the 500 mb chart near San Francisco with a wedge over the Continental Divide and westerlies over Wyoming. Utah's afternoon temperatures were in the low 90's with cumulus present.

Trial B-4: No data available.

Trial B-5, 29 August 1961, 2009 MST, 1910 MST Sunset: 0.2° F, 0.0° F, 9/10 cloud cover, neutral, the flow continued southerly with a high pressure pattern. A closed 1016 mb isobar on the MSL chart was located near the southeast corner of Utah. Relatively low pressures were shown over Idaho and near west Texas at El Paso, but with a wedge over the Texas panhandle. Moisture was increasing in flow from Gulf of California.

Trial B-6, 5 September 1961, 2056 MST, 1858 MST Sunset: +7.52° F, 13.1° F, 5.5° F, 850 mb contour trough over Wyoming, and contour trough over Nevada. Surface charts showed rapidly moving cold front over

southern Idaho and northwest Nevada. The pressure gradient was fairly large, but the temperature gradient was small across the front, as viewed on the MSL projection. Good weather prevailed over Utah with few clouds and southerly winds at the surface. The 2000 MST chart MSL projection showed a wedge east to west over Utah, but with troughs in southern Utah and northwest Nevada. However, winds aloft indicated that the effect of the trough in southern Utah was negligible, and weather was dominated by the wedge over northern Utah. The 500 mb wedge confirmed this. 06/0500 information showed that the front had slowed and remained north of Utah-Nevada-Idaho borders.

Trial B-7, 4 October 1961, 1630 MST, 1811 MST Sunset: +1.1° F, -2.8° F, neutral, becoming diurnally more stable, no clouds, winds 3.6 (2 m) and 4.2 (150'). The MSL pressure pattern was anticyclonic. Relatively high pressure was present over basin with closed centers indicated near Wendover, Jackson, Idaho Falls, and Grand Junction. Winds were near calm over the Dugway Proving Ground generally. The 850 mb constant pressure surface showed ridge contours near Evanston at 0500 MST preceding test. At 1700 MST a ridge described the Elko-Wendover and Salt Lake region with light northwest winds near Salt Lake City. The 700-mb constant-pressure showed a closed high contour over Nevada and northern California at 04/1700 MST.

REMARKS: Coupling of large and smaller scales are expected near 1630, with "crossover" near 1730, an average for this date. This coupling can explain the results and the difference of these results from prediction using a simple line source model.

Trial B-8 (G), 19 October 1961, 1629 MST, 1747 MST Sunset: +2.4° F, +1.0° F, -0.5° F. Moderately stable when the diurnal change is compared with other tests; 6/10 cloud cover; wind speeds 1/2 m; 5.6 mph; 150': 18.8 mph; and 2m, 5.77 MPS. Stable case, diurnal effect not dominant during test. The general synoptic condition would not predict as strong winds as indicated. The mean sea level projection showed a likelihood of a light SW flow generally west of Salt Lake City. The pressure gradient was weak and diurnal changes dominant. A weak thermal trough was north of Dugway and southeast of Wendover. At 19/1400 MST, in the larger view, fronts were remote. At 19/1700 MST, ridges of high pressure dominated southern Utah (Milford), extending both into Nevada and Colorado. Consistent with the large-scale ridge flow or high pressure pattern, steep inversions appeared both before and after the test on morning soundings.

The tendency for the flow to be influenced by the large scale SW flow was evident. Note that in figure 20, Metronics Report No. 97, a sharp turn from 260 degrees beginning at 1745 MST may have helped to increase the sample along the No. 18 line.

Trial B-9, 6 June 1962, 1849 MST, 1959 MST Sunset: 2m: 11.8 mph; 300 ft, 23.9 mph; 1/2 to 50', +0.1° F; 2m-300 ft, 1.3° F, 2/10 cloud cover. A stationary front or trough was aligned east to west through southern Utah, southern Nevada, and western Colorado. Winds were generally from the north on a synoptic map scale: Winds at 1850 MST were from NNE, shifting to ESE to SE after 2300 MST up through 250 feet. Prior events are listed:

850 mb at 1400 MST and 1700 MST, high centered Malad to Twin Falls, or nearly north of DPG. Winds at Ely, Delta, Wendover, and Hill Field were all from N to NNE. At 700 mb, 1400 MST to 1700 MST, trough near a line from Twin Falls to Santa Barbara, counterclockwise flow over northern Utah, indicating that 850 mb pattern was shallow, or less than 5000' thick.

Trial B-10, 7 June 1962, 1733 MST: 11.1 mph (2m), 10.7 (150') mph, -2.5°F, -0.6° F, no clouds. Ridge from 850 mb to 500 mb and above was dominant. The flow identified with the ridge gave clear skies over the Great Basin; stationary front lay across northern Arizona. The features at map-time were:

1700 MST, 850 mb: Ridge dominated Boise-Pocatello-Salt Lake City and Wendover, a cyclic low was over eastern New Mexico.

1700 MST, 700 mb: Ridge covered the Rocky Mountain states west of the Continental Divide, with north winds from eastern Colorado to Saskatchewan.

1700 MST, 500 mb: The ridge gave way to a trough from Las Vegas to Casper, the ridge depth was limited from 700 mb to 500 mb over Utah.

Stability and Shear: Neutral stability and fairly strong shear to the gradient wind level described the test conditions. The coupling was good on all scales. The ascendent of the wind speed was away from Granite Peak, as is usual with moderate flow on this scale.

Test B-11, 12 June 1962, 1951 MST, 2002 MST Sunset: +6.8° F, +10.2° F (1/2m to 300') 7/10 cloud cover, U_h = 5.3 mph, $U_{\frac{1}{2}M}$ = 4.0 mph. At 12/1700 MST, and 850 mb trough was indicated between DPG and Delta. at 12/2300 MST, the 850 mb trough had reformed north of Wendover and Malad area and showed DPG in a southerly flow. Also a former thermal trough southern Utah-Las Vegas through Grand Junction, Ely, Delta, and Evanston was no longer identifiable. Reference reports are consistent with large scale information. See page 28, TR 117.

Test B-12, 21 June 1963, 2050 MST, 2005 MST Sunset: 0.0° F, 0.0° F, no clouds, neutral, 9.0 mph (2m) to 21.2 mph (150'), no cloud cover (clear skies), 24 mph (300'), northerly winds. Over the grid, horizontal wind speed increased eastward. 1930 MST, DPG

local station winds indicated a trend toward northeast from north and increasing speed. 1700 MST westerly ridge flow above 5000', becoming WSW at 10,000 feet, 700 mb. 2300 MST northerly at 5000', and west at 10,000 feet. This was considered a postfrontal situation with the front having been indicated at 21/0500 MST near Wendover.

Trial B-13, 20 January 1964, 2003 MST, 1736 MST Sunset: +2.5° F, +3.6° F, 9/10 cloud cover, moderately stable; wind speeds 12.8/22.0 mph. At 20/2000 MST a warm sector was over Utah with flow from south to southwest, with a low over Oregon and a high over New Mexico. At 20/1700, the 500 mb (19,000') level chart indicated a nearly zonal flow with strong winds from west and ridge in the contour pattern over Utah. From 20/2000 through 20/2400 MST, southerly winds were over DPG with gusts to 18 mph at 2 meters. A cloud deck was at moderate altitude and listed as 10,000 feet, broken.

Trial B-14, 18 March 1964, 1702 MST, 1842 MST Sunset: 2m: 16.4 mph, 150': 25.3 mph, -2.0° of -4.3° F, 5/10 cloud cover. From 1200 MST to 1600 MST, there were northerly winds reported. From 1600 MST to 1900 MST, winds were NNW 10 mph to 15 mph in gusts, some virga scattered to NW to SE, 43° F on test indicating large scale or orogaphic instability. At 1700 MST over DPG the winds were at 5000' north and with ridge flow 8000' north with ridge flow; 16,000' north and with ridge flow the 500 mb trough was just east of SLC, north to south orientation (Salt Lake City to Yellowstone). The corresponding 700 mb trough was just east of Salt Lake City extending to Yellowstone. The 850 mb front was south of the Utah/Arizona border.

Trial BA-1, 8 June 1965, 2329 MST, 2000 MST Sunset: 2m to 96m; +9.5° F, wind speed 0.4 MPS (2M, 210° wind speed) 4.2 MPS at 48 M. 10/10 cloud cover. Sky cover was 10/10 all day, consisting of scattered cumulus with light showers or virga in the vicinity. The direction during the day was mainly from the south near 12 mph, becoming ESE but very light winds after 2300 MST. At 08/1700 MST, the 850 mb level showed a low over most of Nevada and northwestern Utah. The 08/2300 MST surface analysis showed a long low trough which extended from northeast New Mexico to Spokane and across Delta and Wendover, a weak high center which was inclosed to the south in Arizona, and a low pressure over Nevada. At 08/1700, the nearest mb surface chart showed winds SSW over Utah, part of a large circulation centered near Bakersfield. The 500 mb wedge was just east of the Continental Divide aligned north-south Pueblo-Casper-Missoula and in Utah; shallow early morning inversions were consistent with test-time stability, but with a near adiabatic lapse rate overall.

Trial BA-2, 28 June 1966, 2157 MST, 2006 MST Sunset: 2m to 101M: +12.3°F, wind speeds 2m: 155°F, 2.1 mph, 48m: 8.0 MPS, 1/10 cloud cover. At 100 MST, a cool or high pattern was over central Utah and mainly SSW over DPG in the large scale pattern. A trough and stationary front was aligned from Twin Falls to Sacramento, becoming a warm front near Yellowstone. High pressure (28/2000) ridge (MSL projection) was aligned northwest to southeast over New Mexico to Cedar City. From 28/1400 to 28/2300 a front was indicated over Idaho forming a wave with a cold front oriented north-south through central Nevada and northeast from Twin Falls to Billings. The large scale flow 28/1700 MST was from the southeast along a line from Grand Junction to Twin Falls. Also 500 mb ridge was aligned Ely to Salt Lake City which gave SW winds over Utah near 19,000 feet. The large scale was consistent with the grid-scale during the test, even though decoupling and stratification in the lower 300 feet probably took place.

NOTE ON TERMINOLOGY: High, anticyclic, or anticyclonic and ridge are pattern descriptions respectively for pressure, flow and height contours on constant pressure surfaces. They are approximately equivalent at the same time of day and season in their influence on stability if there is coupling between the scales measured. Low-trough cyclic patterns or cyclonic patterns are similarly approximately equivalent and in rough sense are associated with instability.

The diurnal influence is associated with time of sunset or the earlier occurrence of "crossover", a time of change from daytime neutral or unstable conditions to stable conditions through neutral, usually measured by the temperature difference 1/2 to 4 meters and valid in comparison of times only as an average time of change. The "large scale" terminology refers to that scale just larger than the scale of the grid and can be associated with the synoptic map for which data are given as much as sixty miles apart and for hourly intervals. The physical measurements of the scale, synoptic scale, and planetary scale are measured over one station in their respective fields at least to 500 mb, a procedure which is adequate for determining overall stability, under steady or slowly changing conditions. For equivalence of heights, the 850 mb constant pressure surface is near terrain level over most of the Rocky Mountain states. The 700 mb constant pressure surface is near 10,000 feet above mean sea level. The 500 mb constant pressure surface is near 19,000 feet above mean sea level. The exact heights

will depend upon the weather patterns generally dependent upon time and location. The size of the ASG grid used in the B502 tests was sufficient for the cloud encounter with heterogeneous turbulence fields and main flow gradients in the wind fields observed, and significant time variation in average wind. The decoupled cases have been identified with the stable regimes, and coupled cases with neutral to lapse or unstable large scale conditions. For convenience:

2 meters = 6.56 feet, 1/2 meter = 1.61 feet

1 meter = 3.28 feet, 1/2 meter = 1.61 feet

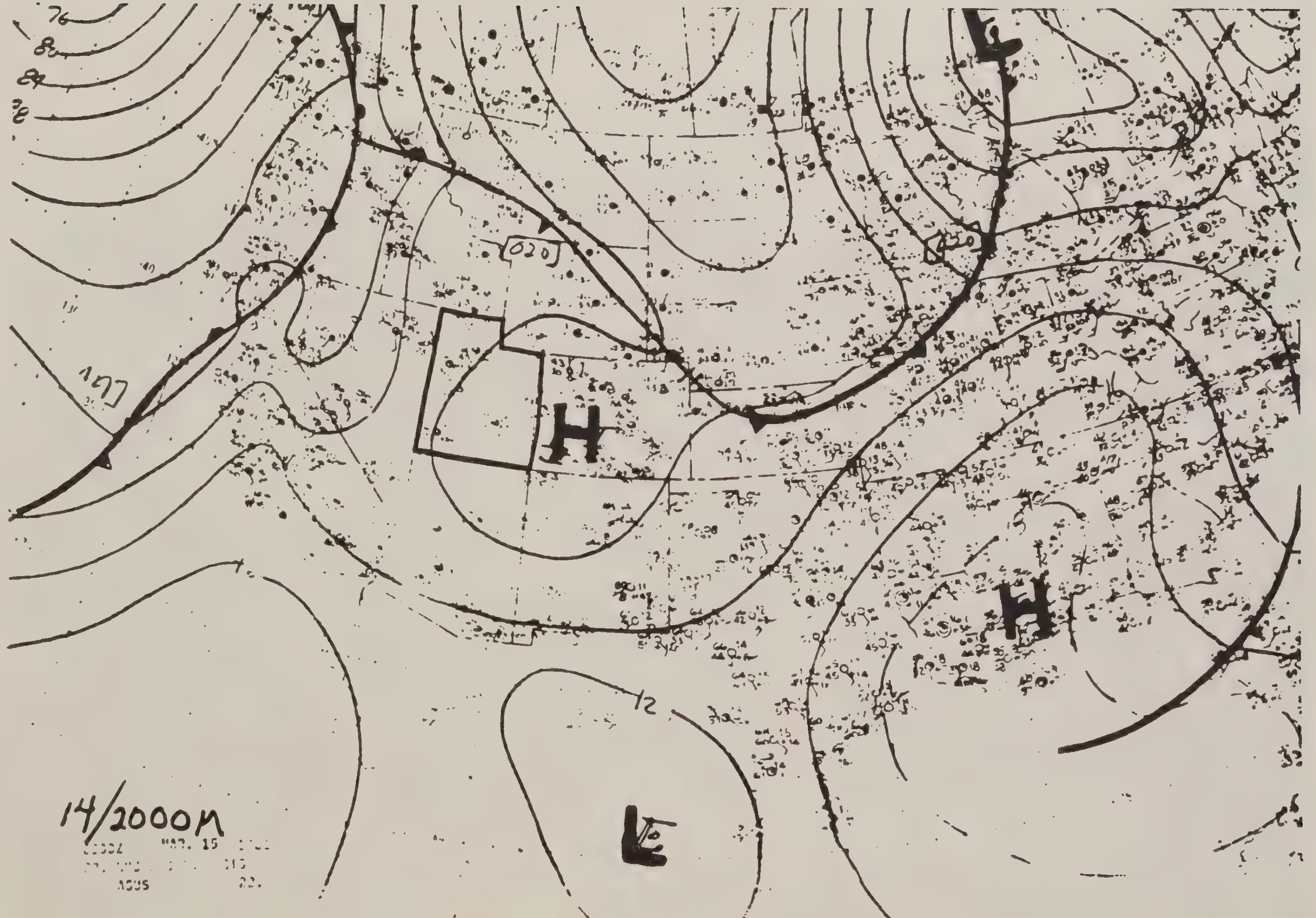

Figure . 14 March 1961, 2000 MST, MSL Surface Chart representing B502B1.

(Note: This figure is included to show a typical MSL surface chart used in the preceding synoptic analyses.)

APPENDIX

XII

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RDT&E PROJECT NO. 1B025001A128
USATECOM PROJECT NO. 5-5-9955-22

DPG PROJECT NO. DR B502 - Phase B

SUPPLEMENTAL TESTS OF DOWNWIND DIFFUSION FROM AERIAL LINE SOURCES

DATA REPORT

BY

JAMES E. FRESE

JUNE 1968

AD 696 368

DUGWAY PROVING GROUND
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509448

DETAILS OF TEST

INTRODUCTION

Original Scope of Testing

The original scope of testing was to perform three trials, each to be conducted under the specific conditions outlined in the second amendment to the Phase B, B502 test plan . The trial conditions specified were:

Trial A: This trial will be a nighttime trial conducted under stability conditions of 0-to-8°F measured between 2 meters and 100 meters with the inversion extending above the height of tracer release. The wind speed will be less than 4.5 meters per second (10 miles per hour) at 2 meters, between 2.2 and 6.7 meters per second (5 and 10 miles per hour) at 45.7 meters (150 feet), and must be operational above 45.7 meters for both aircraft and balloons. This trial will consist of a simultaneous release at 121.9 meters (400 feet) of green FP and a ground release of yellow FP.

Trial B: This trial will also be a nighttime trial but it will be conducted after the nocturnal inversion has become well established. The release height should be between 30.5 and 121.9 meters (100 and 400 feet), preferably at the higher elevation, yet it must be below the thermal cap (as determined by tower ΔT and planesonde data). The wind speed must be operational for both aircraft and balloons. One color of FP will be released from one aircraft; and, approximately 15 minutes later, the other color of FP will be released by another aircraft at the same altitude as the first aircraft.

Trial C: This trial will be conducted during the daytime, well removed from transitional periods. There should be a moderate to strong lapse condition and the wind speed at the 45.7 meter (150 feet) height must be 3.6 meters per second (8 miles per hour) or greater, yet operational for aircraft and balloons. Two aircraft will disseminate green and yellow FP concurrently in this trial--one at 121.9 meters (400 feet) and one at 76.2 meters (250 feet).

Resulting Scope of Testing

The first trial was completed successfully on the second attempt (the first attempt was only partially satisfactory); however, at the beginning of the second trial, a large and unexpected increase in windspeed resulted in the destruction of the balloons that supported the rotorod samplers. These balloons could not be replaced, consequently, the two remaining trials were not completed. The following paragraphs contain the details of testing and results obtained from the two attempts (designated as Trials B-A1 and B-A2) of the first trial.

DETAILS OF TRIALS B-A1 and B-A2

Objectives

2.2.1.1 General. The overall objective of the Phase B, B502 trials was to determine whether or not ground level dosages with 1- to 5-micron particles disseminated under a wide range of stability conditions and release heights covered distances ranging from 16 to 24 kilometers (10 to 15 miles) downwind from elevated and ground level sources.

Specific. The specific objective of each trial was to obtain the following information:

a. The distances from the release line to the first ground level dosage and to the peak dosage;

b. The change in dosage with distance from the source to as far as 24 kilometers (15 miles) downwind;

c. The vertical extent (upper and lower limits) of the cloud at two or more downwind locations; and,

d. The relationship between surface dosage distributions, the vertical extent of the cloud, and the meteorological conditions including wind speed, temperature gradient, wind velocity gradient, and vertical gustiness.

Material and Facilities

Location. Both Trials B-A1 and B-A2 were conducted on the north array of the Aerial Spray Grid (ASG). Only the center

radial (radial 34) was utilized for sampling. The ASG sampling array, as it was used in these trials, is shown in Figure 1.

FP Material. The aerial releases utilized green FP (Lot H-396) and the surface releases utilized yellow FP (Lot H-395). Physical property data describing each lot are contained in Table 1.

Table 1. Summary of FP Lot Data and Amounts Disseminated, Trials B-A1 and B-A2, Phase B, B502.

LOT NUMBER	COLOR	MASS MEAN DIAMETER (microns)	NUMBER OF PARTICLES PER GRAM ($x10^{10}$)	QUANTITY DISSEMINATED (grams)	
				B-A1	B-A2
H-395	Yellow	3.3	1.32	2,872.9	2,684.4
H-396	Green	3.2	1.45	22,224.0	11,587.6

Dissemination Equipment

a. Model D Dry Particulate Disseminator: This disseminator consists mainly of a conical hopper, a notched feed wheel, and a downspout. The material (FP for these trials) contained in the hopper is delivered by gravity flow to the feed wheel which delivers it at a uniform rate to the downspout. At this point, the material is aerosolized by secondary air entering through a series of ports in the downspout. For Trial B-A1 the disseminator was mounted in a U-6A aircraft and for Trial B-A2 the disseminator was mounted in a JU-8D aircraft.

b. Mark IV Skilblower Aerosol Generator: This disseminator consists of essentially the same type of components as the Model D except that an electrically driven blower performs the aerosolization rather than secondary air fed into a downspout. Two Skilblowers were used in each trial, each mounted on the bed of a 3/4-ton truck.

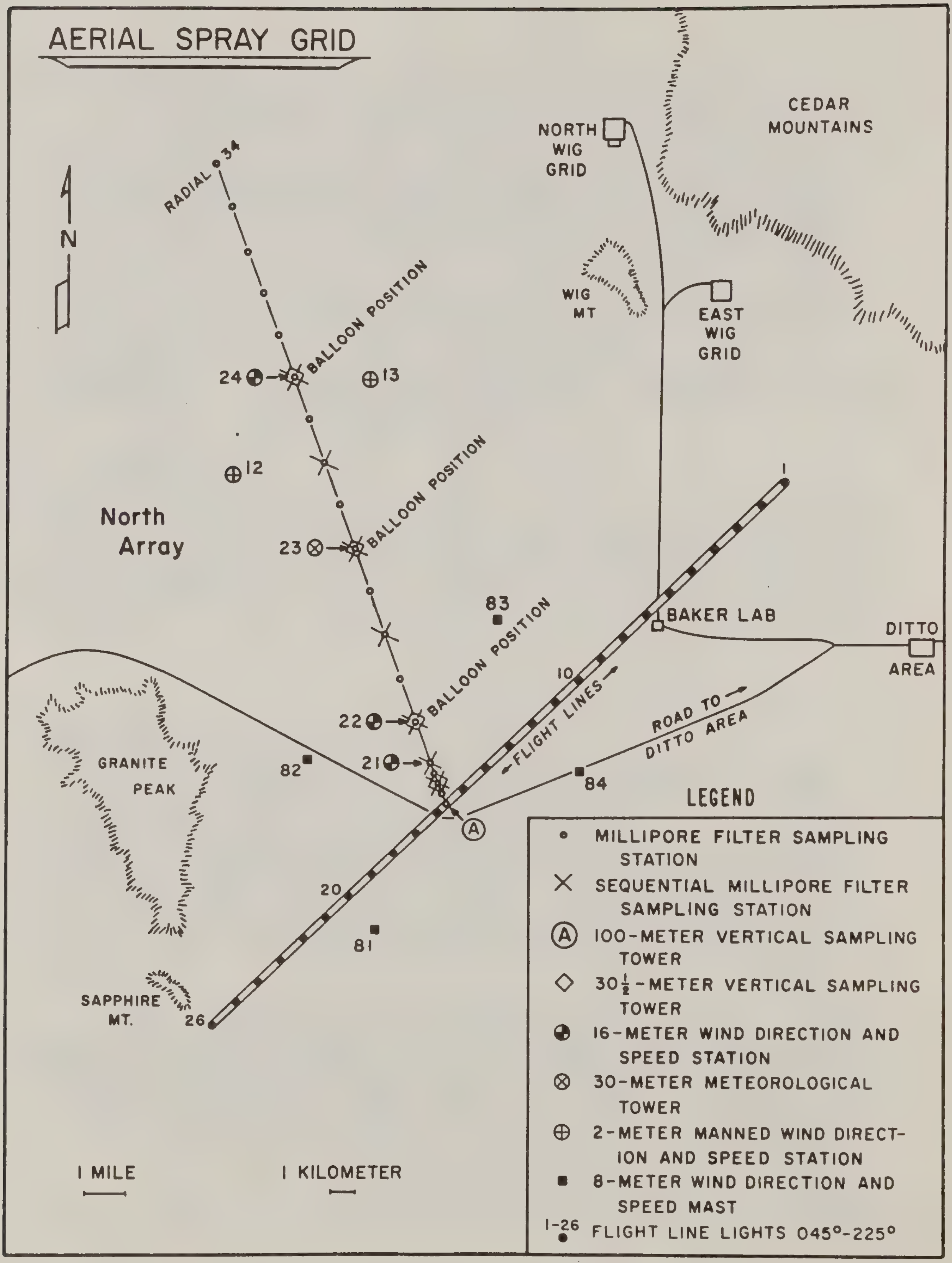

Figure 1. Flight Line, FP Sampling Array and Meteorological Sampling Array Utilized in Trials B-A1 and B-A2, Phase B, B502.

FP Sampling Equipment.

a. Membrane Filters: Membrane filters were mounted in standard metal holders with an exposed circular filter of 18.54mm in diameter. The filters were aspirated at a rate of 6 liters of air per minute.

b. Rotorods: Model 60-A rotorod samplers were equipped with H-shaped FP collecting rods coated with a thin layer of high vacuum silicone grease. Each rotorod operated at a rate of 2400 rpm sweeping a total of 41.3 liters of per minute.

c. Sequential Sampling Unit: Windsoc sequentialized sampling units were equipped with ten membrane filter samplers. Eight of the samplers were operated sequentially, each for a fifteen minute interval. The ninth sampler also was operated in sequence but was continued longer than the fifteen minute period to assure sampling during the entire passage of the cloud. The tenth sampler operated as a total dosage sampler. It was activated simultaneously with the first sampler and not deactivated until the end of the ninth sampling period. Each filter was aspirated at a rate of 6 liters per minute.

Methods

Control Samplers. Membrane filter samplers were operated for periods of 45 and 75 minutes just prior to dissemination in order to obtain estimates of background FP present during testing. These samplers were located at the 1.5 meter (5 foot) level at the 3.2-, 6.4-, 9.7-, 12.9-, and 16.1-kilometer (2-, 4-, 6-, 8-, and 10-mile) downwind sampling positions.

Tower Sampling. Aerosol sampling was performed with membrane filters placed at two-meter intervals on the ASG Tower. The first sampler was located two meters above the ground and the last sampler was located at the 92-meter level. Four 30.5 meter (100 foot) towers were utilized for downwind profile sampling. These towers were located at positions indicated in Figure 1. Membrane filter samplers were positioned at 1.5-, 6.1-, 10.7-, 15.2-, 19.8-, 24.4-, and 29.0-meter (5-, 20-, 35-, 50-, 65-, 80-, and 95-foot) heights for Trial B-A1 and positioned at 4.6-, 9.1-, 13.7-, 18.3-, 22.9-, 27.4-, and 32.0-meter (15-, 30-, 45-, 60-, 75-, 90-, and 105-foot) heights on an extended tower for Trial B-A2. At each of the top three positions

located on each of the last three 30.5 meter towers, an additional aerosol sample was obtained with a rotorod sampler. This was performed to obtain data pertaining to the relative collection efficiencies of the two aerosol sampling devices. All samplers were activated for a time estimated to be sufficient to assure complete passage of the aerosol cloud.

Horizontal Sampling. To obtain ground level dosage estimates, aerosol sampling with membrane filters was performed 1.5 meters (5 feet) above ground level at the positions indicated in Figure 1. These samplers were activated for a time period estimated to be sufficiently long to assure sampling of the entire aerosol cloud. Sequential sampling with membrane filters was also performed at this height at the indicated positions shown in Figure 1. Sampling times for the sequential units are outlined in Paragraph 2.2.2.4.c.

Balloon Supported Sampling. Balloons tethered by 304.8 meters (1000 feet) of cable were placed at the 3.2-, 9.7-, and 16.1-kilometer (2-, 6-, and 10-mile) positions shown in Figure 1. Each cable had 25 rotorod samplers attached at 10.7 meter (35 foot) intervals starting at 41.1 meters (135 feet) from the lower end of the cable.

Meteorological Sampling. Positions for the meteorological sampling towers and stations are indicated in Figure 1. For Trial B-A1, meteorological data at the ASG Tower were recorded in the following manner: Windspeed and temperature data were obtained at the $\frac{1}{2}$-, 1-, 2-, 4-, 8-, 16-, 32-, 48-, 64-, 88-, and 96-meter positions. Wind direction data were obtained at the 2-, 16-, 32-, 64-, and 96-meter levels and vertical wind directions data were obtained at the 2- and 16-meter levels. Essentially the same positions were used for Trial B-A2 except for: (1) a 101-meter position was substituted for the 88- and 96-meter positions; (2) the 48-meter position was added to the wind direction data; and, (3) 16-, 32-, and 101-meter positions were used to measure vertical wind direction. A single 30-meter meteorological sampling tower was located at position 23 (see Figure 1). For Trial B-A1, windspeed data were obtained on this tower at the $\frac{1}{2}$-, 2-, 4-, 8-, 16-, and 30-meter heights and wind direction at the 2- and 30-meter heights. For Trial B-A2, windspeeds and direction data were obtained at the same heights and temperature measurements were made at the $\frac{1}{2}$-, 2-, 4-, 8-, 16-, and 30-meter heights. Windspeed and wind were obtained at the 2- and 16-meter levels at meteorological stations 21, 22, and 24 in Trial B-A1 and at meteorological

stations 22 and 24 in Trial B-A2 (see Figure 1). In both trials, windspeed and wind direction data were obtained at the 8-meter level at meteorological stations 81, 82, 83, and 84 (see Figure 1). Two-meter windspeed and wind direction data were obtained at meteorological stations 12 and 13 in Trial B-A1 and at meteorological stations 12, 13, and 21 in Trial B-A2. In each trial, cloud cover, surface temperature, and relative humidity observations were made periodically at several selected points throughout the grid array. Pibals were used to obtain wind speed and direction data just prior to and during downwind passage of the aerosol. Pibal data were obtained at meteorological stations 12, 13, 21, 22, 23, 24, 81, 82, 83, and 84 in Trial B-A1 and at the same stations, except for 21, in Trial B-A2. These data were obtained to heights extending well above the aerosol sampling heights. In each trial, temperature measurements, obtained with thermocouples placed at 45.6-meter intervals on each balloon cable, were made just prior to and during sampling.

Clinometer Readings. In Trial B-A1, the average angle of elevation with respect to the ground of each support balloon was ascertained and recorded at the end of each fifteen minute period from dissemination time to the end of sampling. No clinometer data were obtained in Trial B-A2.

Dissemination Procedures. In each trial, simultaneous aerosol and ground releases were made under stable nighttime conditions. In Trial B-A1, the elevated line source was generated from a U-6A aircraft flying at an altitude (above ground) of 55 meters and at a speed of 54 meters per second. In Trial B-A2, the elevated line source was generated from a JU-8D aircraft flying at an altitude (above ground) of 90 meters and at a speed of 77 meters per second. In each trial, dissemination was made along the 22.5-kilometer (14-mile) flight line shown in Figure 1. The ground release for each trial commenced the moment the aircraft passed the ASG Tower. This release was performed by two 3/4-ton-trucks driving in opposite directions from the center of the indicated flight line (see Figure 1). The approximate speed of each vehicle was 30 miles per hour (13.4 meters per second).

Results

2.2.4.1 Meteorological Data. Comprehensive summaries of the meteorological data obtained at each meteorological sampling station during each trial are given in Appendix I, Tables 19

through 28. A complete set of meteorological data is on file at Test Design and Analysis Office, Dugway Proving Ground, Utah. Table 2 briefly summarizes the meteorological regime present during each trial.

Table 2. Summary of General Meteorological Conditions Present During Trials B-A1 and B-A2, Phase B, B502.[a]

CATEGORY	TRIAL NUMBER	
	B-A1	B-A2
Temperature (^{o}F)		
Surface	67°	75°
Indicated Height	63° at 1 m	73° at $\frac{1}{2}$ m
Relative Humidity (% at indicated height)	32 at 1 m	26 at $\frac{1}{2}$ m
Temperature Gradient (F^{o} for indicated interval)	+9.5 2 m to 96 m	+12.3 2 m to 101 m
Average Wind Speed (meters/second)	0.4 at 2 m	2.1 at 2 m
	4.2 at 48 m	8.0 at 48 m
Average Wind Direction (degrees at 2 meters)	210	155
Cloud Cover	10/10	1/10

[a]Values taken at dissemination time near the 100-meter sampling tower.

Clinometer Data. Estimates of the "blow down" angles (expressed in fifteen minute averages) were obtained in Trial B-A1. These values are listed in Table 3. No clinometer data were available for Trial B-A2.

Dissemination Results. Table 4 summarizes the dissemination data obtained in Trials B-A1 and B-A2 and also contains the times and dates each was performed. In Trial B-A1,

Table 3. Clinometer Reading Averages Obtained for Trial B-A1, Phase B, B502.

ESTIMATED ANGLES OF ELEVATION (°) OF BALLOONS WITH RESPECT TO THE GROUND FOR INDICATED TIME INTERVAL AT INDICATED SAMPLING POSITION					
3.2-km (2-mile) Position		9.7-km (6-mile) Position		16.1 km (10-mile) Position	
Time[a]	Angle	Time	Angle	Time	Angle
Z[b] + 1	60	Z + 16	52	Z - 2	63
Z + 16	54	Z + 31	46	Z + 13	66
Z + 31	55	Z + 46	49	Z + 58	64
Z + 46	55	Z + 61	43	Z + 73	68
Z + 61	48	Z + 76	41	Z + 88	66
Z + 76	44	ND	-	Z + 103	62
ND[c]	-	ND	-	Z + 118	62
ND	-	ND	-	Z + 133	75
ND	-	ND	-	Z + 148	74
ND	-	ND	-	Z + 163	78
ND	-	ND	-	Z + 178	74
ND	-	ND	-	Z + 193	75
ND	-	ND	-	Z + 208	74
ND	-	ND	-	Z + 223	70
ND	-	ND	-	Z + 238	80
ND	-	ND	-	Z + 253	72
ND	-	ND	-	Z + 268	73
ND	-	ND	-	Z + 283	75

[a]Time values indicate end of 15-minute averaging period.

[b]Z indicates function time of test.

[c]ND indicates no data.

Table 4. Summary of Dissemination Data, Trials B-A1 and B-A2, Phase B, B502.

CATEGORY	TRIAL NUMBER AND TYPE OF RELEASE					
	B-A1			B-A2		
	Aerial Release	Surface Release		Aerial Release	Surface Release	
Date of Dissemination	8 June 65	8 June 65		28 June 66	28 June 66	
Time Dissemination Began	2329	2326	2327	2157	Not Recorded	
Type of Vehicle	U-6A[a]	3/4-Ton Truck[b]	3/4-Ton Truck[c]	JU-8D[a]	3/4-Ton Truck[b]	3/4-Ton Truck[c]
Speed of Vehicle (m/s)	54.0	13.4	13.4	77.0	13.4	13.4
Height of Dissemination (m)	56	2	2	90	2	2
Length of Dissemination Line (m)	23,000	6,600	5,100	9,700	6,800	5,000
Length of Dissemination Time (sec)	417.8	492	383	125	510	372
Rate of Dissemination (gm/sec)	53.2	3.2	3.4	92.7	3.3	2.7

(Continued)

Table 4. Summary of Dissemination Data, Trials B-A1 and B-A2, Phase B, B502.

CATEGORY	TRIAL NUMBER AND TYPE OF RELEASE					
	B-A1			B-A2		
	Aerial Release	Surface Release		Aerial Release	Surface Release	
Amount of FP Disseminated (gm)	22,224	1,585	1,288	11,588	1,673	1,012
FP Lot Number	H-396	H-395	H-395	H-396	H-395	H-395
FP Color	Green	Yellow	Yellow	Green	Yellow	Yellow

(Concluded)

[a]Aircraft traveled in a westerly direction.

[b]Truck traveled in an easterly direction.

[c]Truck traveled in a westerly direction.

unit one (vehicle headed in an easterly direction) of the ground-level dissemination inadvertently began dissemination eighty seconds earlier than unit two. This produced two separated ground-level disseminated lines rather than the desired single line. Consequently, the trial was repeated. In Trial B-A2, the aerial disseminator malfunctioned after operating normally for a distance of approximately ten km (six miles).

2.2.4.4 FP Control Sampling Results. The number of green and yellow FP particles collected during the control sampling period (conducted immediately prior to each dissemination) are presented in Table 5.

Table 5. Results of FP Background Control Sampling, Trials B-A1 and B-A2, Phase B, B502.

SAMPLING POSITION	GREEN FP RECOVERIES (particles)		YELLOW FP RECOVERIES (particles)	
	Trial B-A1	Trial B-A2	Trial B-A1	Trial B-A2
3.2-km (2-mile)	7	13	0	8
6.4-km (4-mile)	4	48	39	18
9.7-km (6-mile)	0	0	8	6
12.9-km (8-mile)	12	3	150	6
16.1-km (10-mile)	0	13	3	18

Estimates of FP Total Dosage Recoveries Obtained at Ground-Level Sampling Positions. Estimates of the total number of green and yellow FP particles recovered during each trial at each of the various downwind ground-level sampling positions are given in Figures 2, 3, 4, and 5.

Estimates of FP Total Dosage Recoveries Obtained at the ASG Tower. Estimates of the total number of green and yellow particles recovered during each trial at each of the various sampling positions on the ASG Tower are given in Appendix I, Tables 7 and 8. Also shown in Tables 7 and 8 are the dosage per unit source strength values (D/Q), obtained by dividing each estimated recovery value by the sampler flow rate and the estimated effective source strength.

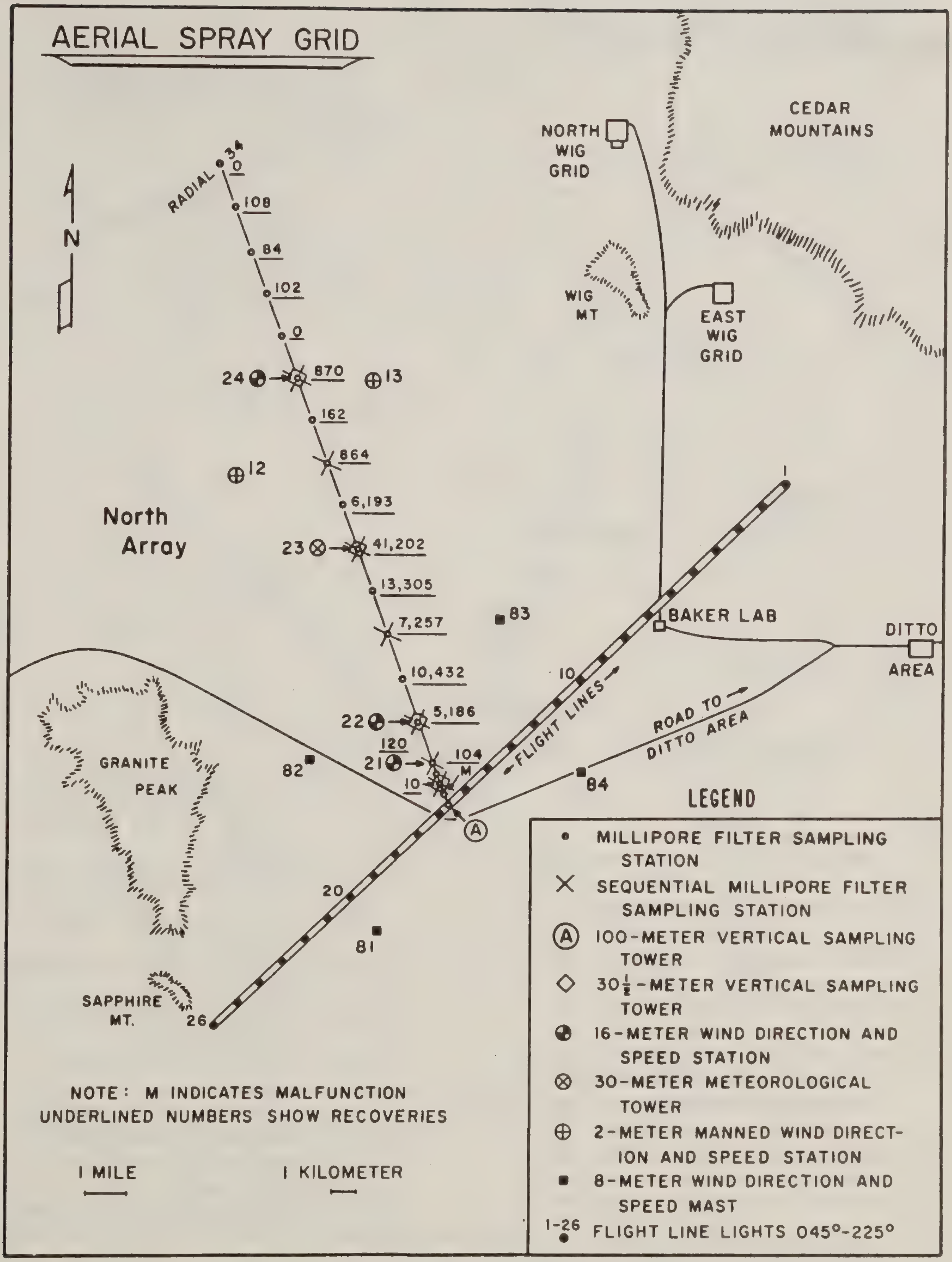

Figure 2. Green FP Recoveries Obtained at 1.5-meters (5-feet) for Trial B-A1, Phase B, B502.

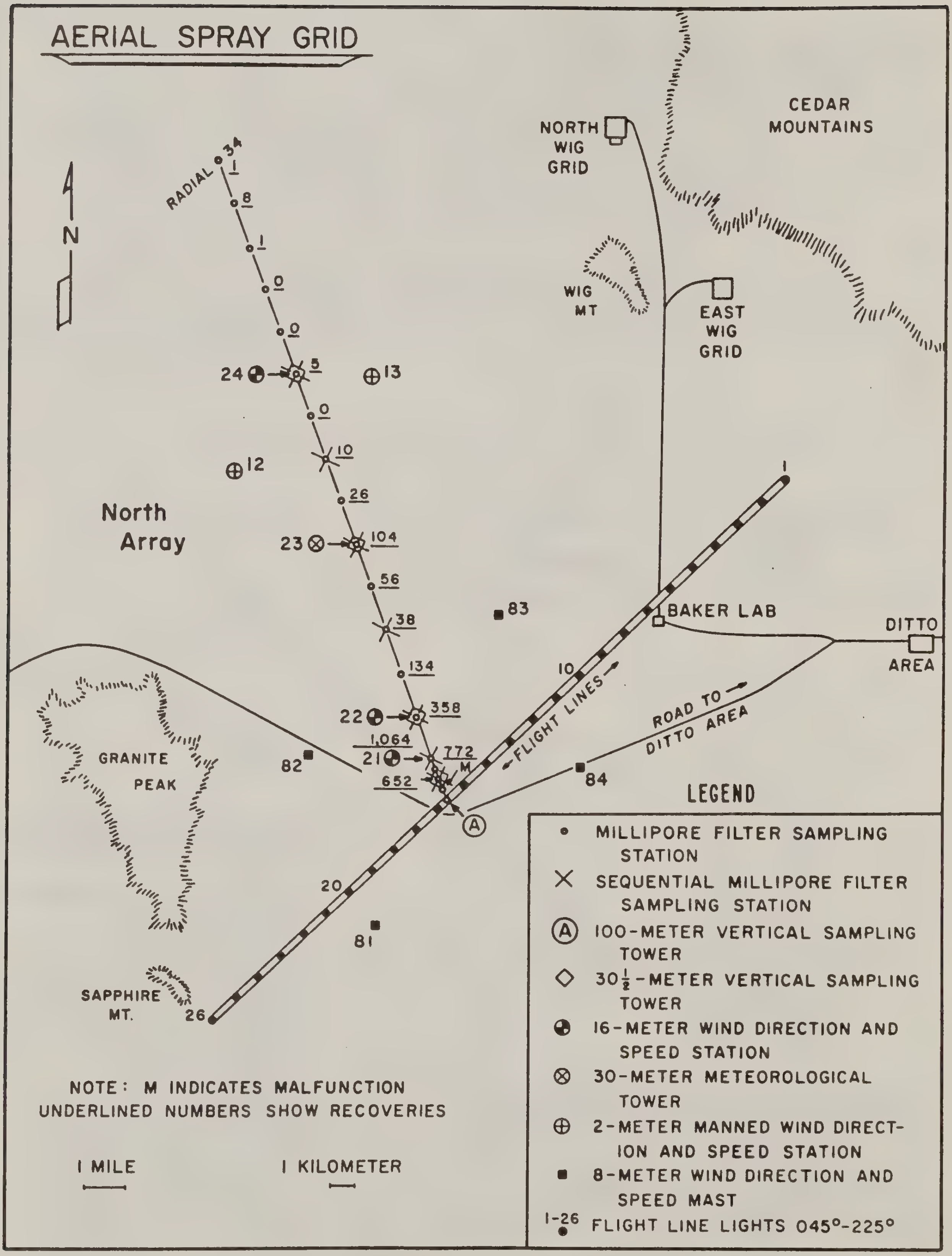

Figure 3. Yellow FP Recoveries Obtained at 1.5-meters (5-feet) for Trial B-A1, Phase B, B502.

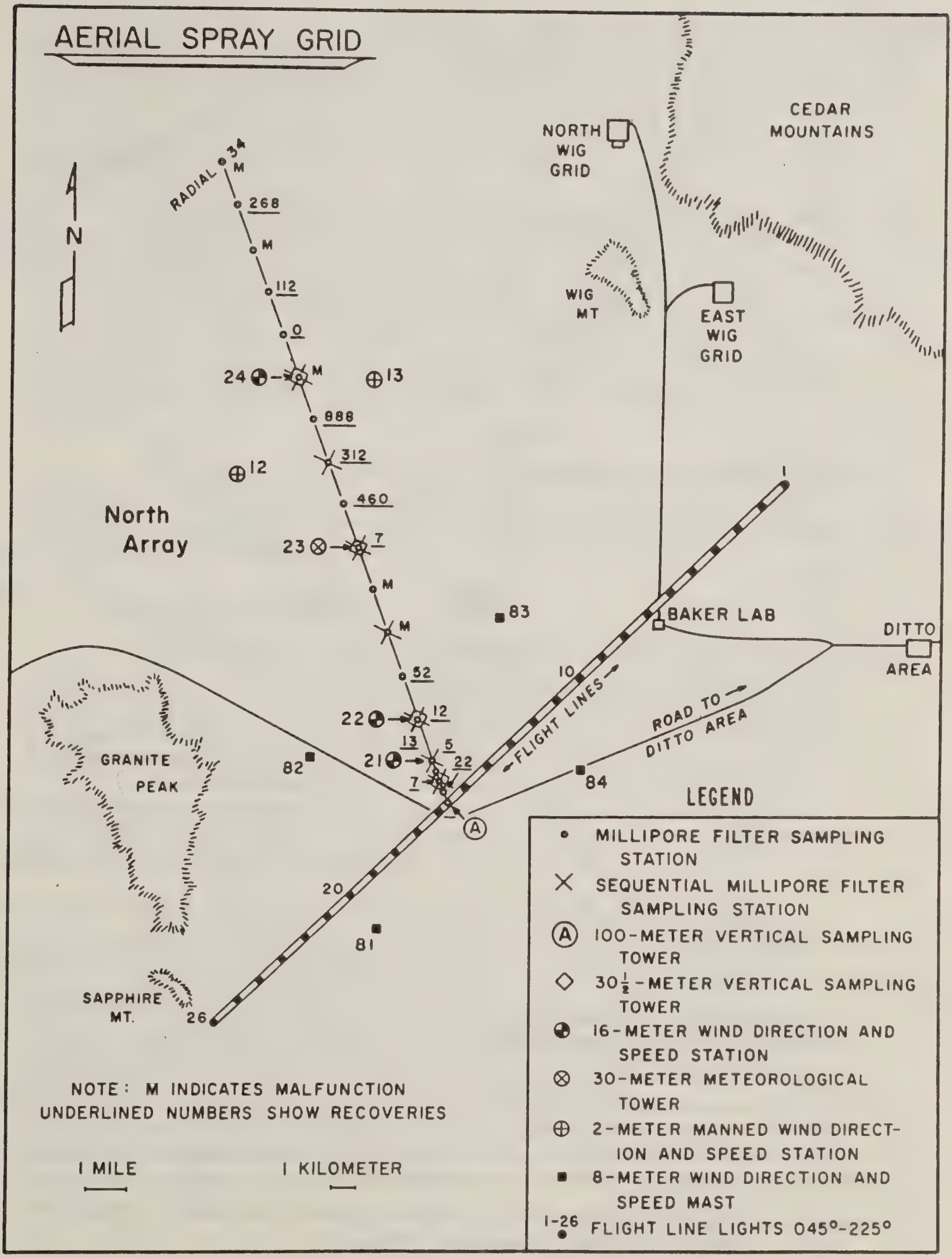

Figure 4. Green FP Recoveries Obtained at 1.5-meters (5-feet) for Trial B-A2, Phase B, B502.

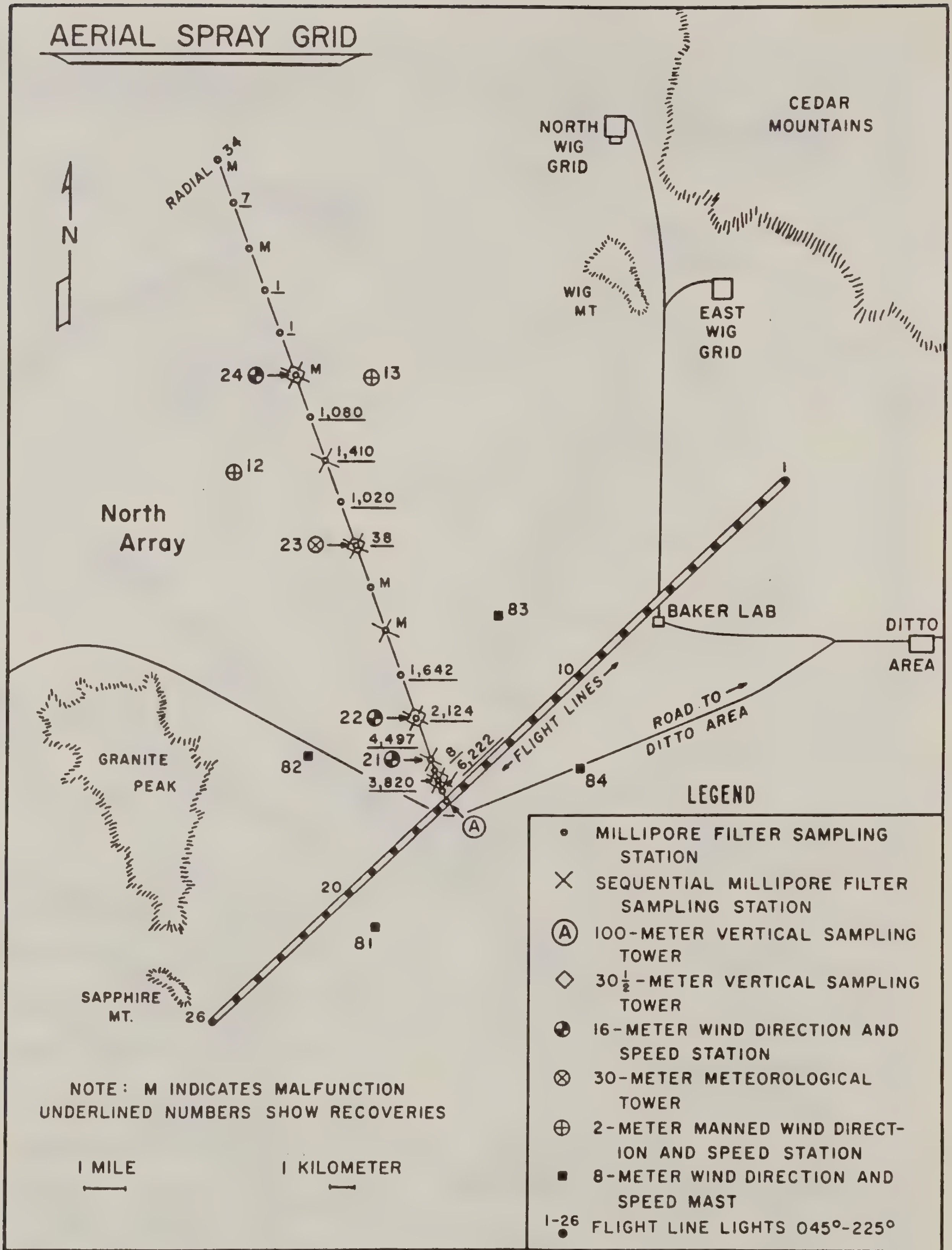

Figure 5. Yellow FP Recoveries Obtained at 1.5-meters (5-feet) for Trial B-A2, Phase B, B502.

Estimates of FP Total Dosage Recoveries Obtained at the Downwind Towers. Estimates of the total number of green and yellow FP particles recovered during each trial at the various sampling stations located on the four downwind towers are given in Appendix I, Tables 9 and 10. Also shown are the corresponding D/Q values determined for each of the various samplers.

Estimates of FP Total Dosage Recoveries Obtained with Rotorod Samplers. Estimates of green and yellow FP total dosage recoveries obtained with rotorod samplers mounted on the three balloon cables are given in Appendix I, Tables 11 and 12. Estimates of green and yellow FP total dosage recoveries obtained with rotorods mounted on three downwind towers are given in Appendix I, Table 13. Also shown in Tables 11, 12, and 13 are the corresponding D/Q values determined for each of the various samplers.

Estimates of FP Dosage Recoveries Obtained with Sequential Samplers. Estimates of the total number of green and yellow FP particles recovered by membrane-filter samplers operated sequentially are given in Appendix I, Tables 14, 15, 16, and 17.

Analyses of Results

Ground-Level Dosage Recoveries. Recovery data of FP material released by aircraft were visually examined to obtain estimates of the downwind distance to aerosol "touchdown" and the downwind distance to the peak dosage. For Trials B-A1 and B-A2, aerosol touchdown was estimated to have occurred at the 1.2-km (3/4-mile) station and at the 4.8-km (6-mile) station, respectively.[1] Peak dosage recoveries were estimated to have occurred at the 9.7-km (6-mile) station in Trial B-A1 and at the 14.5-km (9-mile) station in Trial B-A2.[2]

Estimation of the Rotorod Collection Efficiency. Rotorods placed adjacent to membrane filters provided a basis for calculating the rotorod collection efficiency (relative to the membrane filter collection efficiency). The reference dosage was obtained by dividing the membrane filter recovery value by the membrane filter sampler flow rate of six liters of air per minute. The rotorod dosage was obtained by dividing

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[1]The observed value of the touchdown distance is simply the first downwind station where recoveries were obtained, and are consequently expected to underestimate the true value due to possible background interference.

[2]The observed value of the peak dosage distance is simply that distance where the largest value occurred.

the rotorod recovery by 41.3 liters per minute--the estimated volume of air swept out per minute by the rotorod sampler. The ratio between the rotorod dosage and membrane filter dosage is the estimated rotorod collection efficiency.

Total recoveries, dosages, and ratios expressed as percentages are given for each sampling position in Appendix I, Table 13. To summarize these data, a median efficiency value was determined for each FP color in each trial.[1] An unexplained marked difference in magnitude of efficiency estimates for the two trials precluded estimates from pooled trial results. In Trial B-A1, the median efficiency for yellow FP was 40 percent and for green FP 35 percent. In Trial B-A2, the median efficiency was 2.5 percent for yellow FP and 2.0 percent for green FP. Due to the small sample size and large variability between individual values, little confidence can be placed on each median value per se. Re-examination of the data failed to provide an explanation for the wide trial-to-trial variability.

Rotorod Sampling Heights. The angle of each balloon with respect to the ground at its respective anchor point was determined by averaging the clinometer data over the estimated period of aerosol passage as determined by sequential sampling data. Heights of individual samplers were determined by applying the sine of the estimated angle to the cable distance measured from the bottom end of the cable to the sampler. The catenary of the cable was disregarded. For Trial B-A2, no clinometer data were available; therefore, a median value of 60°, determined from previous Phase B testing, was applied. Estimated sampling heights for each set of balloon supported samplers are given for each trial in Appendix I, Table 18.

Effective Source Strengths. The estimated effective source strength (Q) obtained for each dissemination was calculated by means of the equation:

$$Q = E \frac{RC}{S}$$

where:

E = Estimated disseminator efficiency;

R = Rate of dissemination (grams/second) of the disseminator;

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[1]Only those ratios where the recoveries of either membrane filter or rotorod samplers exceeded 50 particles were used to estimate the median.

C = Estimated mean FP concentration (particles/gram); and,

S = Speed of vehicle transporting the disseminator (meters/second).

From results of testing[1] conducted at DPG, dissemination efficiency, using FP Lot H-395 with the Mark IV aerosol generator, was estimated as 75 percent, and using FP Lot H-396 with the Model D disseminator, was estimated as 89 percent. Table 6 lists each effective source strength obtained for each trial. The value obtained for the surface releases are averages of effective source strengths obtained for the two generators.

Table 6. Estimates Effective Source Strength Values Obtained for Trials B-A1 and B-A2, Phase B, B502.

TYPE OF RELEASE	ESTIMATED EFFECTIVE SOURCE STRENGTH FOR INDICATED TRIAL (particles x 10^{10}/meter)	
	Trial B-A1	Trial B-A2
Aerial	1.25	1.55
Surface	0.24	0.22

Vertical Distribution Dosage Contours. In order to make meaningful trial-to-trial comparisons, recoveries must be expressed in terms that are independent of both the effective source strength and the sampling rate. Total recoveries obtained in each trial were, therefore, converted to D/Q units. These values, plotted on a vertical cross-section of the sampling lines, are shown in Figures 6, 7, 8, and 9. Also shown in these figures are the equal dosage contour lines. Due to the variability of the data used to estimate the D/Q units the contour lines were smoothed considerably and many of the values lay outside their respective contours. The outermost contour (100 D/Q units) can be considered as outlining the upper and lower boundary (vertical extent) of the aerosol cloud's path as it moved downwind. Values smaller than 100 D/Q units were quite likely due to background contamination (as indicated by the pretest control samplers) and were not considered as the result of cloud passage.

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[1]Unpublished test results obtained for FP Lot H-395 in DPG Test B501 and for Lot H-396 in DPG Test B775

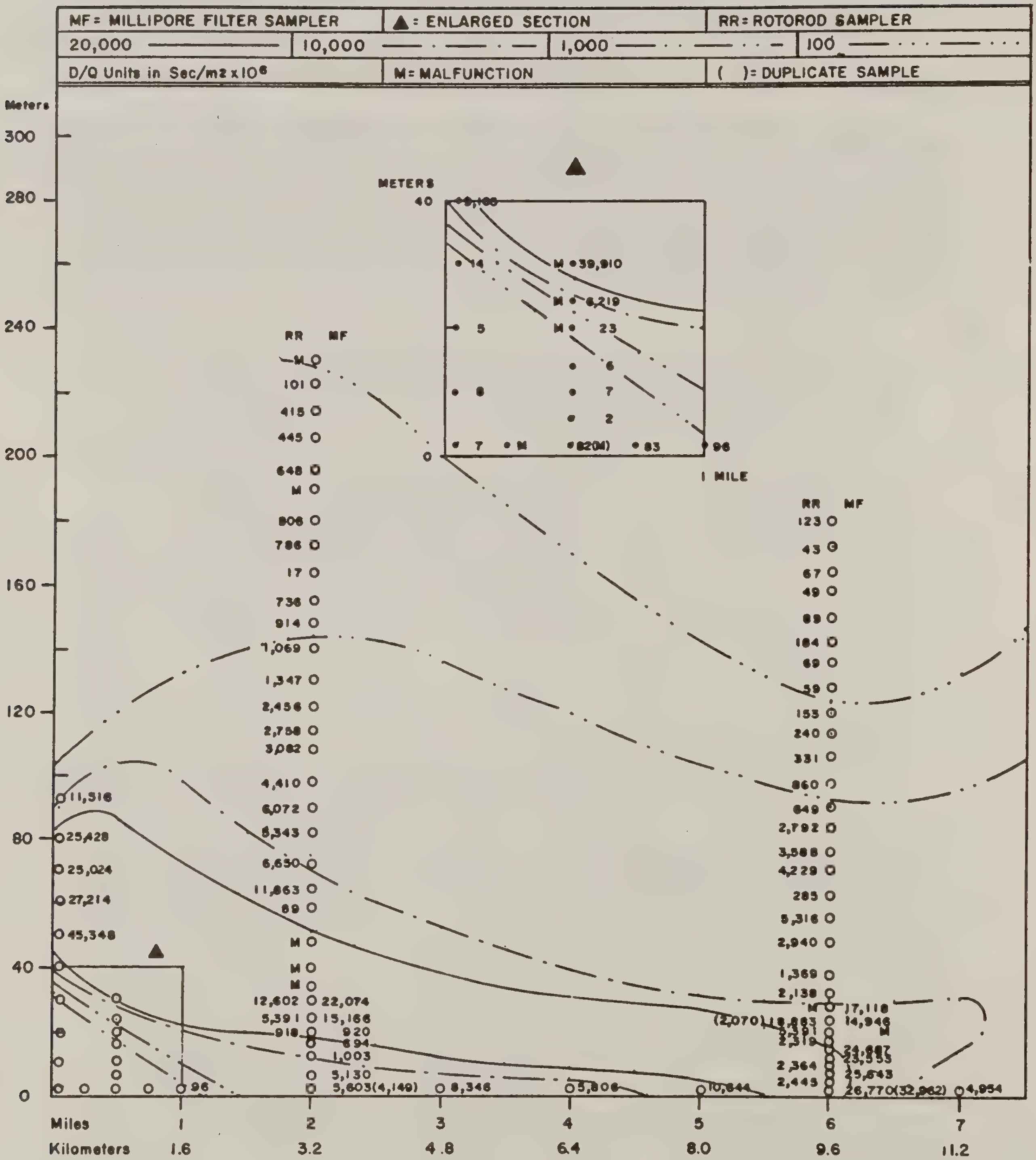

Figure 6. Green FP Vertical Distribution Dosage Contours Obtained in Trial B-A1, Phase B. (NOTE: Only every tenth sampling station indicated for ASG Tower at 0 kilometers).

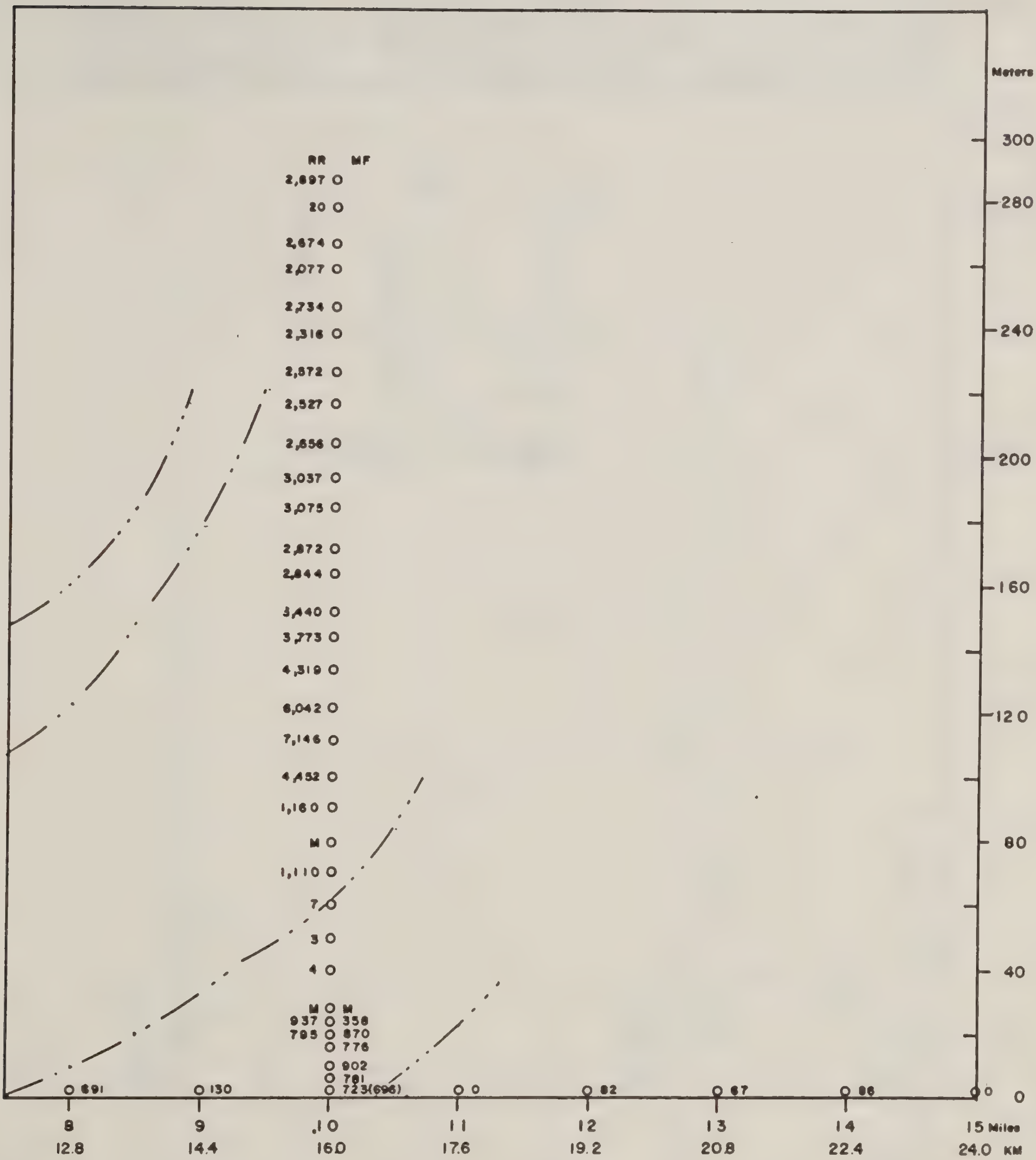

Figure 6. (Continued)

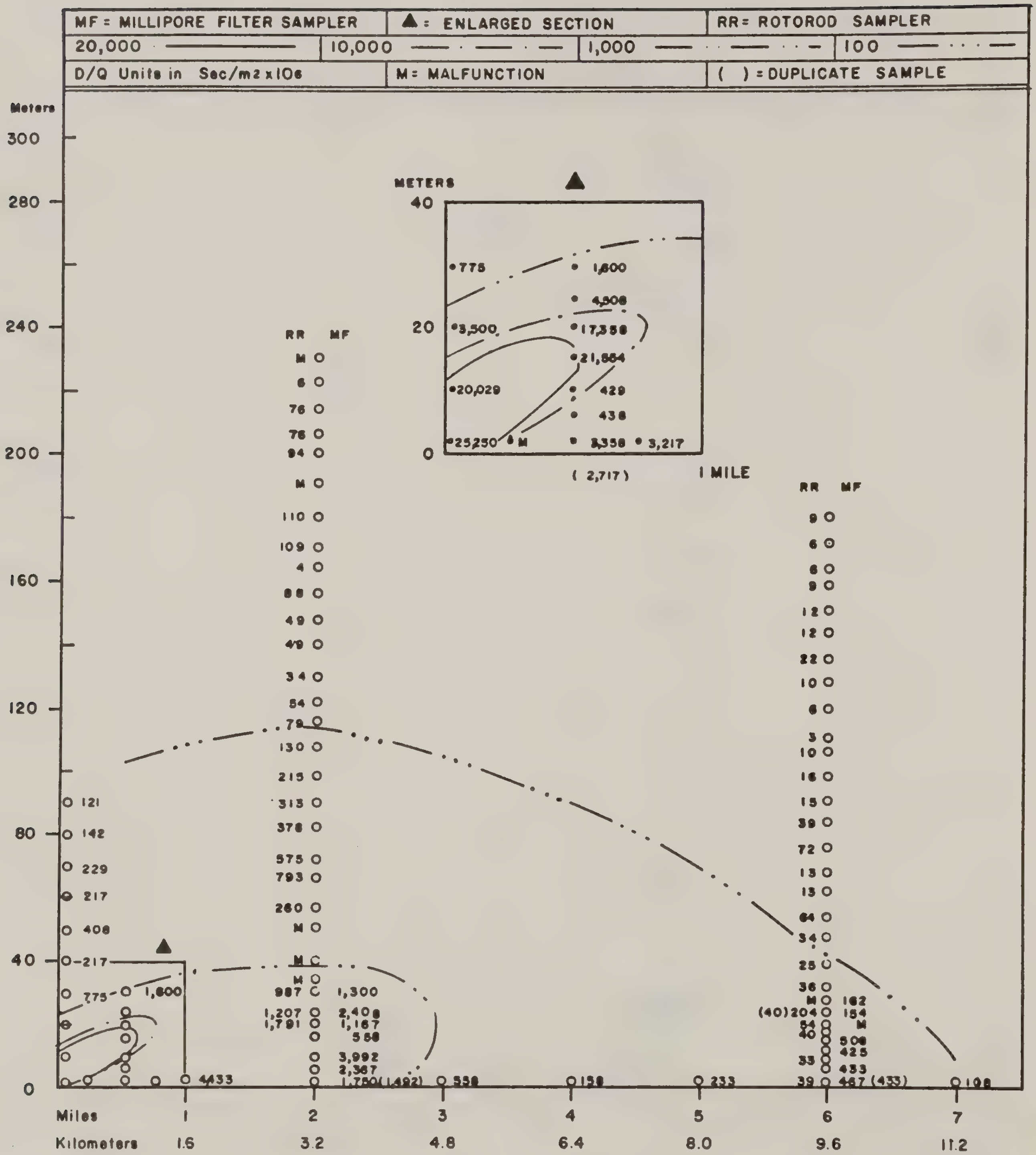

Figure 7. Yellow FP Vertical Distribution Dosage Contours Obtained in Trial B-A1, Phase B, B502. (NOTE: Only every tenth station indicated for ASG Tower at 0 kilometers.)

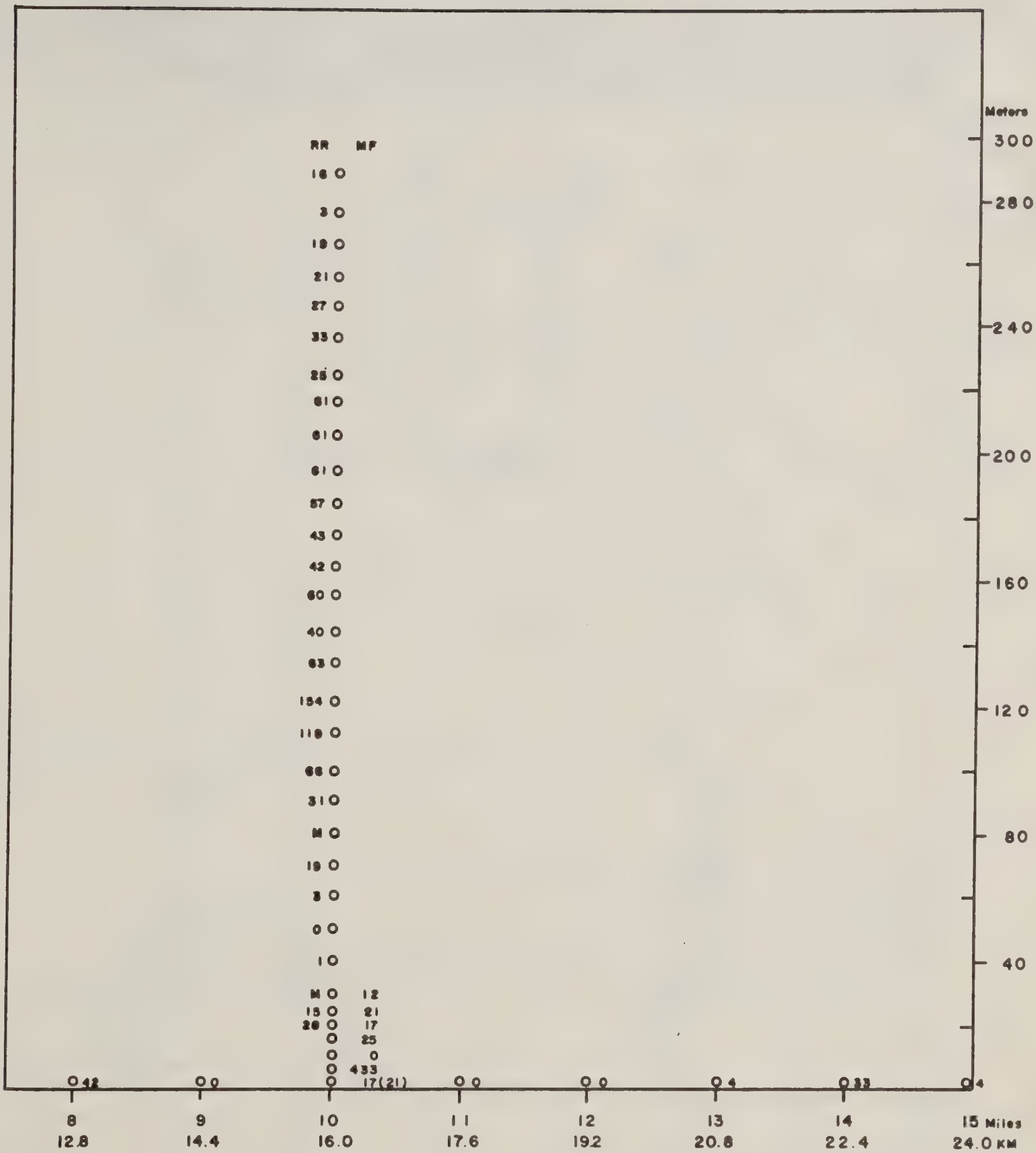

Figure 7. Continued.

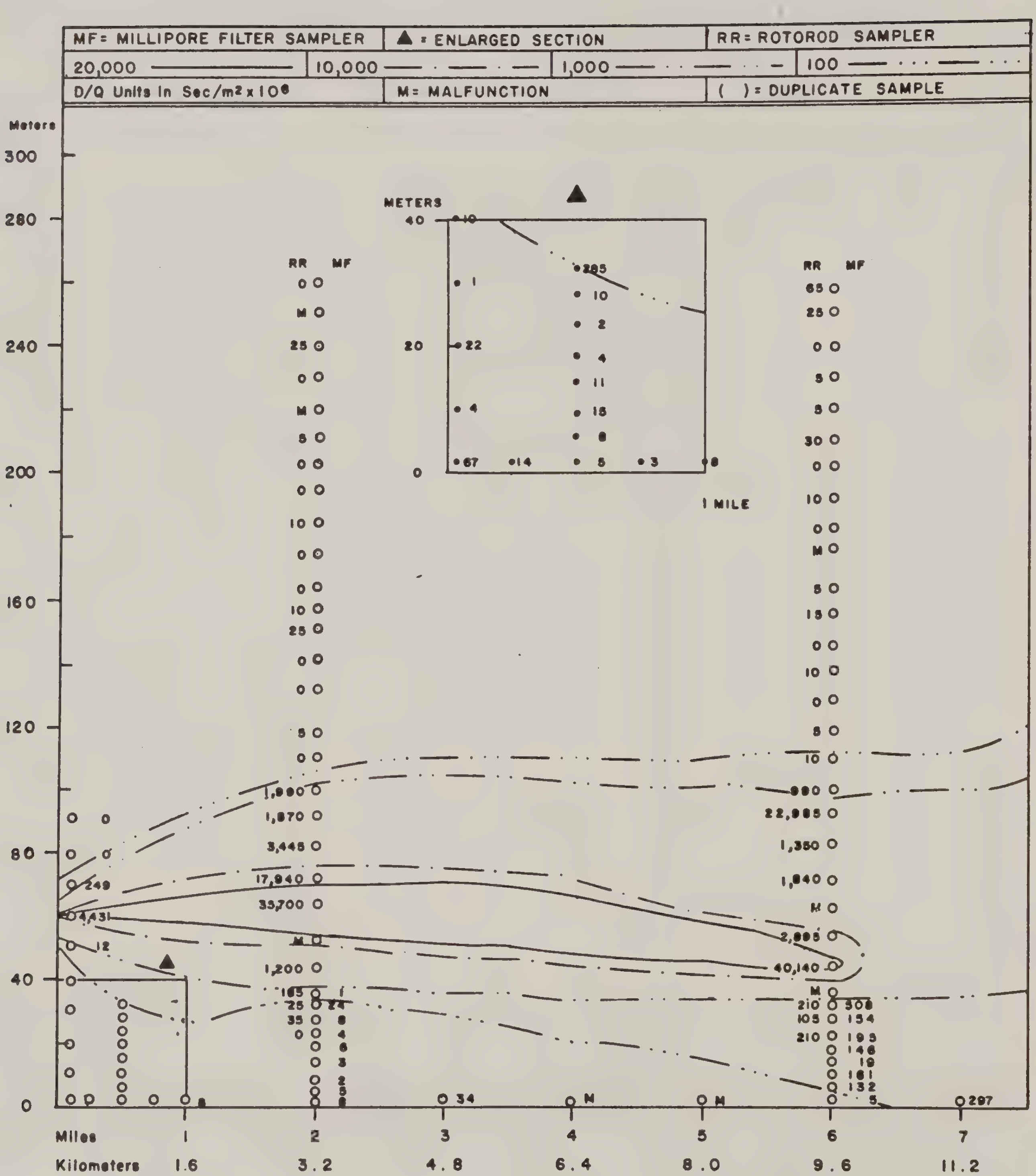

Figure 8. Green FP Vertical Distribution Dosage Contours Obtained in Trial B-A2, Phase B, B502. (NOTE: Only every tenth station indicated for ASG Tower at 0 kilometers.)

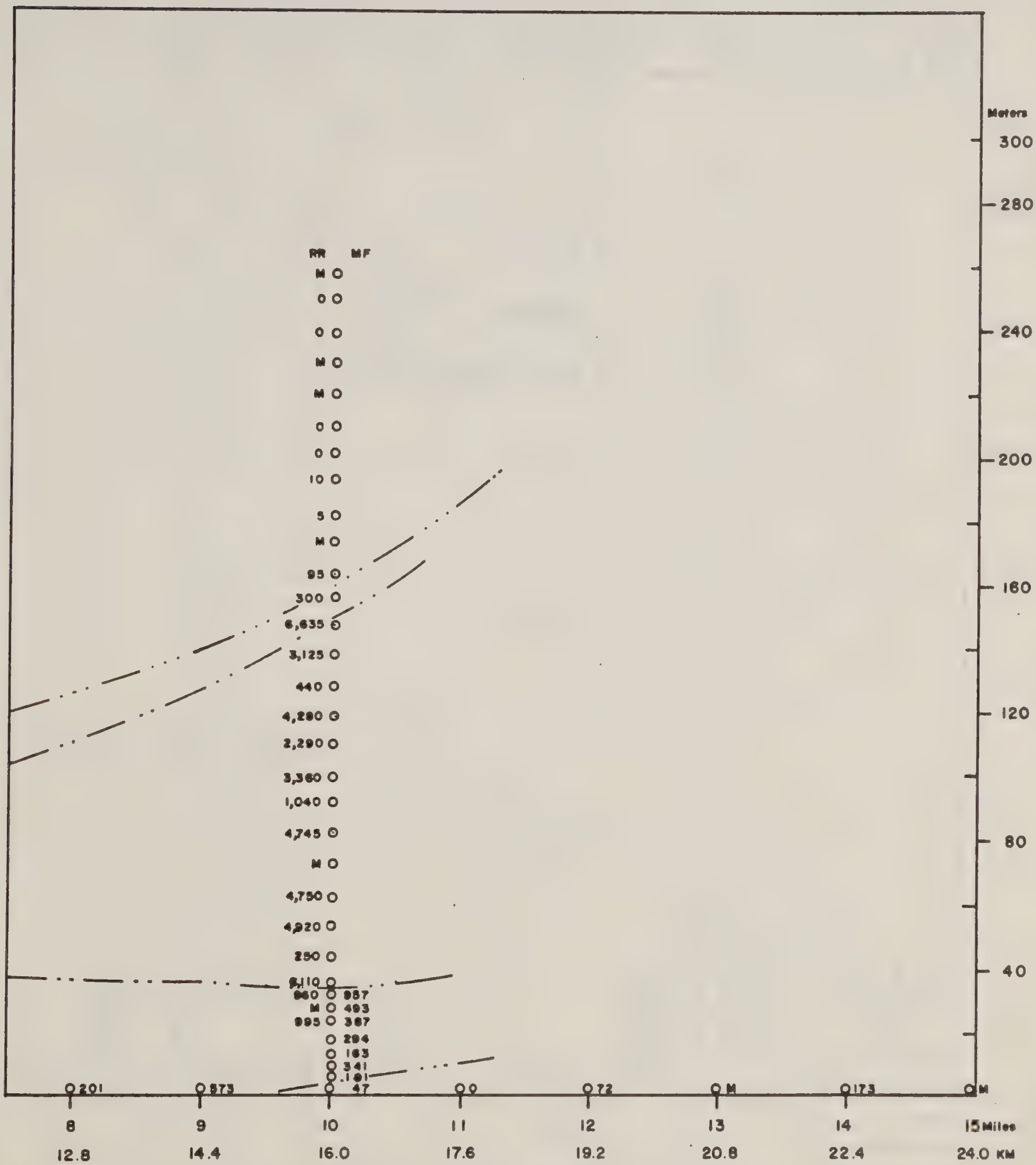

Figure 8. Continued.

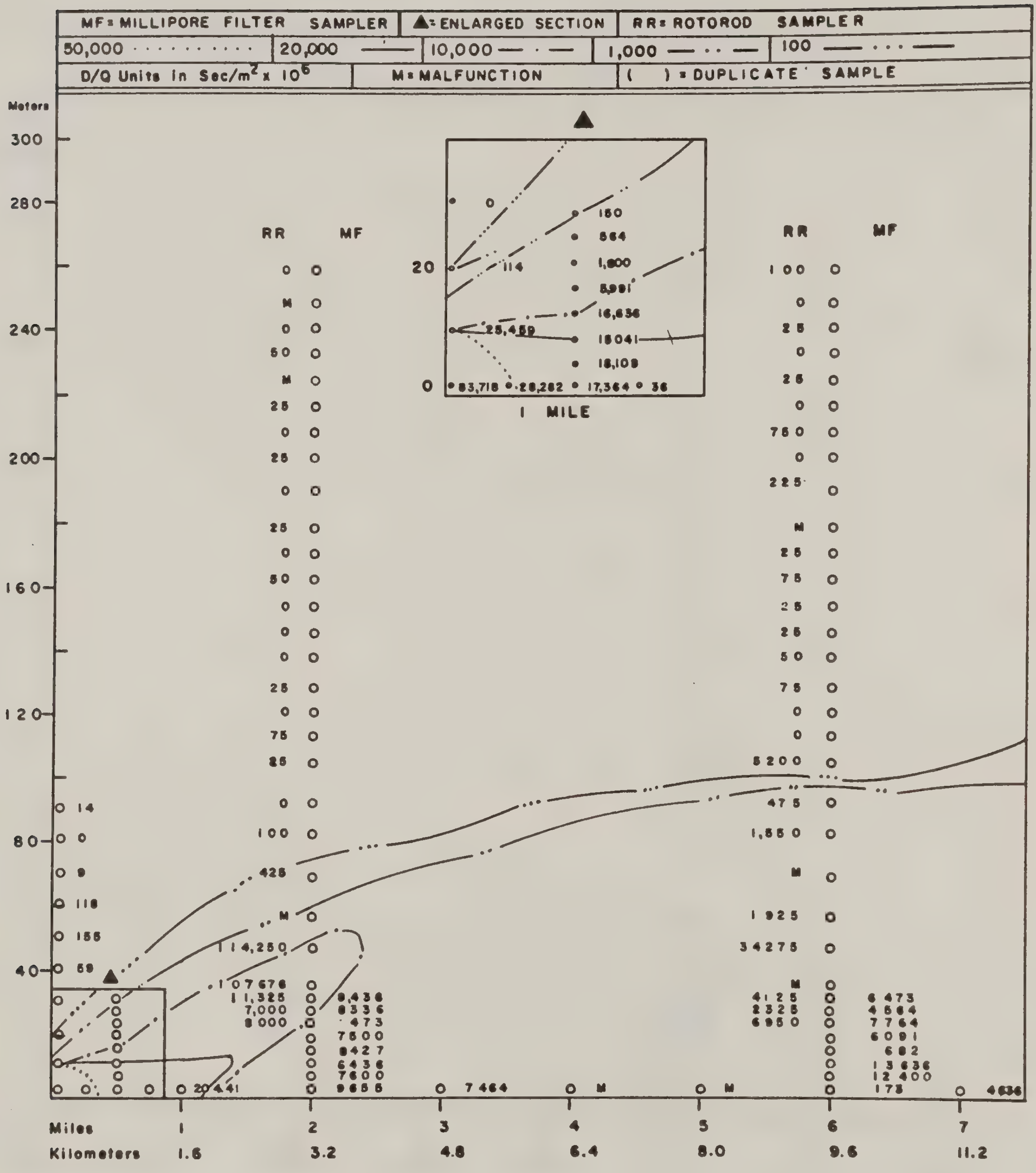

Figure 9. Yellow FP Vertical Distribution Dosage Contours Obtained in Trial B-A2, Phase B, B502. (NOTE: Only every tenth station indicated for ASG Tower at 0 kilometers.)

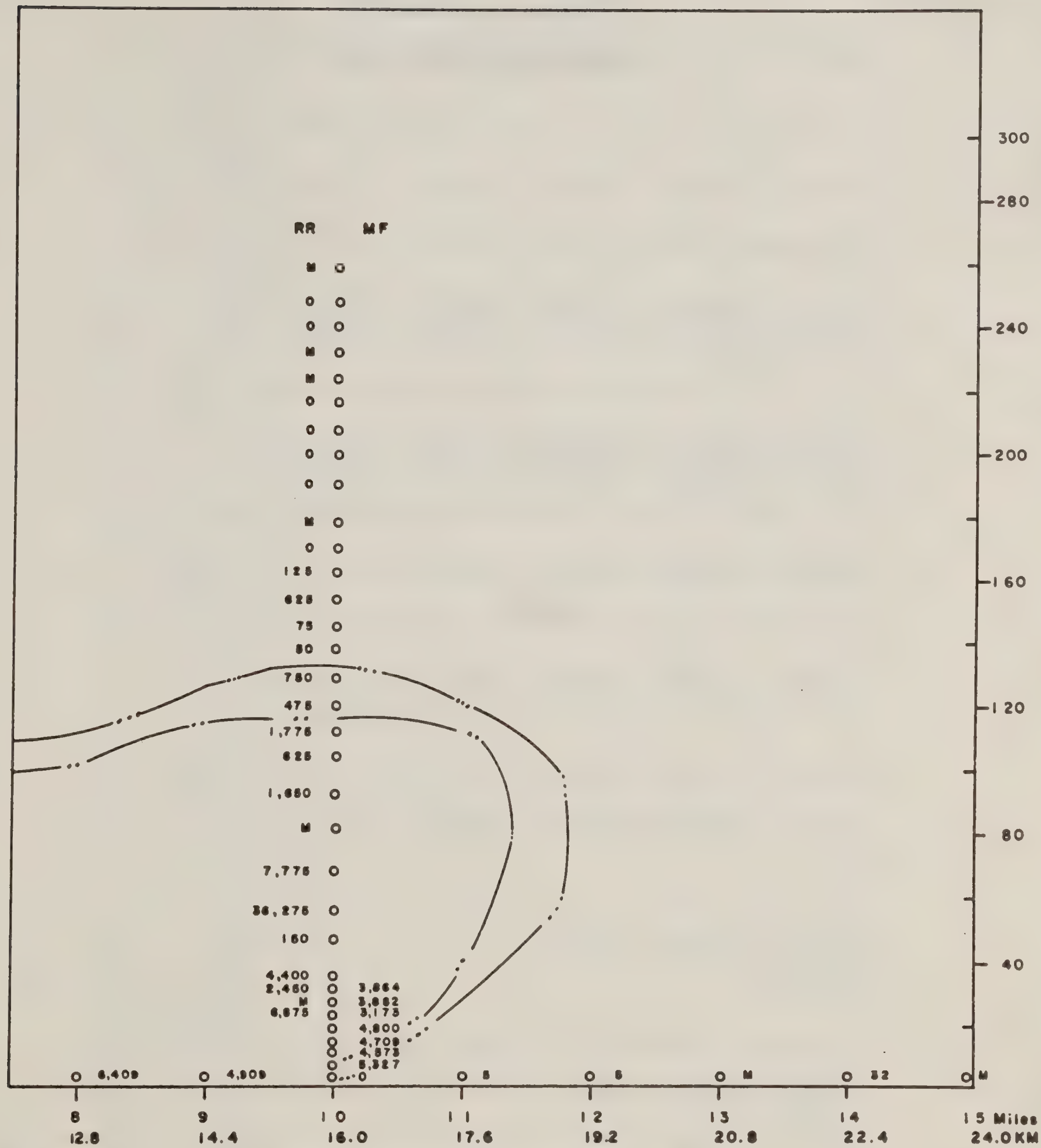

Figure 9. Continued.

SECTION 3. APPENDICES

APPENDIX I. TEST DATA

Table 7. ASG Tower Recoveries of Green and Yellow FP Expressed in Total Particles Collected and in D/Q Units, Trial B-A1, Phase B, B502.

SAMPLING LEVEL	GREEN FP		YELLOW FP		SAMPLING LEVEL	GREEN FP		YELLOW FP	
(meters)	Total Particles	D/Q Units ($sec/m^2 x 10^6$)	Total Particles	D/Q Units ($sec/m^2 x 10^6$)	(meters)	Total Particles	D/Q Units ($sec/m^2 x 10^6$)	Total Particles	D/Q Units ($sec/m^2 x 10^6$)
2	9	7	6,060	25,250	48	43,373	34,698	101	421
4	3	2	8,623	35,929	50	56,685	45,348	98	408
6	3	2	6,367	26,529	52	49,758	39,806	146	608
8	5	4	5,527	23,029	54	68,669	54,935	120	500
10	10	8	4,807	20,029	56	50,234	40,187	110	458
12	0	0	4,045	16,854	58	58,134	46,507	152	633
14	1	1	3,910	16,292	60	34,017	27,214	52	217
16	0	0	200	833	62	33,172	26,538	64	267
18	4	3	1,076	4,483	64	41,533	33,226	100	417
20	6	5	840	3,500	66	28,502	22,802	63	262
22	0	0	586	2,442	68	29,620	23,696	75	312
24	0	0	350	1,458	70	31,280	25,024	55	229
26	0	0	212	883	72	41,843	33,474	106	442
28	12	10	246	1,025	74	48,032	38,426	37	154
30	18	14	186	775	76	38,307	30,646	36	150
32	84	67	156	650	78	38,111	31,289	48	200
34	168	134	63	262	80	31,785	25,428	34	142
36	168	134	89	371	82	32,290	25,832	26	108
38	406	325	49	204	84	22,080	17,664	23	96
40	11,381	9,105	52	217	86	21,930	17,544	35	146
42	45,584	36,467	70	292	88	16,287	13,030	22	92
44	42,681	34,145	43	179	90	16,320	13,056	27	112
46	38,699	30,959	61	254	92	14,395	11,516	29	121

Table 8. ASG Tower Recoveries of Green and Yellow FP Expressed in Total Particles Collected and in D/Q Units, Trial B-A2, Phase B, B502.

SAMPLING LEVEL (meters)	GREEN FP Total Particles	GREEN FP D/Q Units ($sec/m^2 x10^6$)	YELLOW FP Total Particles	YELLOW FP D/Q Units ($sec/m^2 x10^6$)	SAMPLING LEVEL (meters)	GREEN FP Total Particles	GREEN FP D/Q Units ($sec/m^2 x10^6$)	YELLOW FP Total Particles	YELLOW FP D/Q Units ($sec/m^2 x10^6$)
2	104	67	18,418	83,718	48	4	3	1	5
4	24	15	14,137	64,259	50	18	12	34	155
6	18	12	12,370	56,227	52	19	12	13	59
8	9	6	6,204	28,200	54	6	4	4	18
10	6	4	5,601	25,459	56	1,498	966	9	41
12	10	6	1,652	7,509	58	13,601	8,775	28	127
14	9	6	564	2,564	60	6,868	4,431	26	118
16	12	8	72	327	62	4,234	2,732	16	73
18	15	10	65	295	64	546	352	11	50
20	34	22	25	114	66	4,470	2,884	8	36
22	17	11	16	73	68	2,531	1,633	10	45
24	25	16	1	5	70	386	249	2	9
26	0	0	0	0	72	5	3	9	41
28	26	17	26	118	74	43	28	37	168
30	2	1	0	0	76	2	1	6	27
32	3	2	3	14	78	6	4	0	0
34	2	1	0	0	80	0	0	0	0
36	6	4	3	14	82	0	0	4	18
38	8	5	6	27	84	0	0	5	23
40	15	10	13	59	86	2	1	3	14
42	0	0	0	0	88	5	3	0	0
44	0	0	0	0	90	11	7	29	132
46	4	3	0	0	92	0	0	3	14

Table 9. Downwind Tower Recoveries of Green and Yellow FP Expressed in Total Particles Collected and in D/Q Units, Trial B-A1, Phase B, B502.

SAMPLING LEVEL	0.8 km DOWNWIND TOWER				3.2 km DOWNWIND TOWER			
	GREEN FP		YELLOW FP		GREEN FP		YELLOW FP	
(meters)	Total Particles	D/Q Units (sec/m^2x10^6)	Total Particles	D/Q Units (sec/m^2x10^6)	Total Particles	D/Q Units (sec/m^2x10^6)	Total Particles	D/Q Units (sec/m^2x10^6)
1.5	102	82	806	3,358	7,004	5,603	420	1,750
6.1	3	2	105	438	6,413	5,130	568	2,367
10.7	9	7	103	429	1,254	1,003	958	3,992
15.2	7	6	5,173	21,554	868	694	134	558
19.8	29	23	4,166	17,358	1,150	920	280	1,167
24.4	7,774	6,219	1,082	4,508	18,958	15,166	578	2,408
29.0	49,888	39,910	384	1,600	27,593	22,074	312	1,300

SAMPLING LEVEL	9.7 km DOWNWIND TOWER				16.1 km DOWNWIND TOWER			
	GREEN FP		YELLOW FP		GREEN FP		YELLOW FP	
(meters)	Total Particles	D/Q Units (sec/m^2x10^6)	Total Particles	D/Q Units (sec/m^2x10^6)	Total Particles	D/Q Units (sec/m^2x10^6)	Total Particles	D/Q Units (sec/m^2x10^6)
1.5	33,463	26,770	112	467	904	723	4	17
6.1	32,054	25,643	104	433	976	781	104	433
10.7	29,441	23,553	102	425	1,128	902	0	0
15.2	30,859	24,687	122	508	970	776	6	25
19.8	M[a]	M	M	M	1,088	870	4	17
24.4	18,682	14,946	37	154	448	358	5	21
29.0	21,395	17,116	39	162	9	7	3	12

[a]Malfunction.

Table 10. Downwind Tower Recoveries of Green and Yellow FP Expressed in Total Particles Collected and in D/Q Units, Trial B-A2, Phase B, B502.

SAMPLING LEVEL	0.8 km DOWNWIND TOWER				3.2 km DOWNWIND TOWER			
	GREEN FP		YELLOW FP		GREEN FP		YELLOW FP	
(meters)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)
4.6	13	8	3,984	18,109	7	5	1,672	7,600
9.1	24	15	3,309	15,041	3	2	1,416	6,436
13.7	17	11	3,660	16,636	4	3	1,854	8,427
18.3	6	4	1,318	5,991	9	6	1,650	7,500
22.9	3	2	396	1,800	6	4	104	473
27.4	16	10	124	564	13	8	1,834	8,336
32.0	442	285	33	150	37	24	1,856	8,436

SAMPLING LEVEL	9.7 km DOWNWIND TOWER				16.1 km DOWNWIND TOWER			
	GREEN FP		YELLOW FP		GREEN FP		YELLOW FP	
(meters)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)
4.6	204	132	2,728	12,400	296	191	1,172	5,327
9.1	250	161	3,000	13,636	528	341	1,006	4,573
13.7	29	19	15	682	252	163	1,036	4,709
18.3	226	146	1,340	6,091	456	294	1,056	4,800
22.9	302	195	1,708	7,764	600	387	689	3,173
27.4	238	154	1,004	4,564	764	493	854	3,882
32.0	788	508	1,424	6,473	1,484	957	850	3,864

Table 11. Rotorod Recoveries of Green and Yellow FP Expressed in Total Particles Collected and in D/Q Units, Trial B-A1, Phase B, B502.

SAMPLER POSITION[a]	3.2 km BALLOON POSITION				9.7 km BALLOON POSITION				16.1 km BALLOON POSITION			
	GREEN FP		YELLOW FP		GREEN FP		YELLOW FP		GREEN FP		YELLOW FP	
	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)
1	NS[b]	-	-	-	7,393	2,445	26	39	11	4	1	1
2	NS	-	-	-	7,152	2,364	22	33	10	3	0	0
3	NS	-	-	-	7,016	2,319	27	40	21	7	2	3
4	268	89	174	260	6,263	2,070	27	40	3,359	1,110	13	19
5	35,886	11,863	531	793	6,466	2,138	24	36	NS	-	-	-
6	20,117	6,650	385	575	4,140	1,369	17	25	3,510	1,160	21	31
7	16,164	5,343	253	378	8,894	2,940	23	34	13,466	4,452	44	66
8	18,369	6,072	210	313	16,082	5,316	43	64	21,616	7,146	80	119
9	13,339	4,410	144	215	862	285	9	13	18,276	6,042	103	154
10	9,323	3,082	87	130	12,793	4,229	9	13	13,064	4,319	42	63
11	8,343	2,758	53	79	10,853	3,588	48	72	11,414	3,773	27	40
12	7,428	2,456	36	54	8,447	2,792	26	39	10,407	3,440	40	60
13	4,075	1,347	23	34	1,964	649	10	15	8,603	2,844	28	42
14	3,235	1,069	33	49	2,603	860	11	16	8,689	2,872	29	43
15	2,765	914	33	49	1,001	331	7	10	9,303	3,075	38	57
16	2,225	736	59	88	726	240	2	3	9,188	3,037	41	61
17	50	17	3	4	463	153	4	6	8,034	2,656	41	61
18	2,377	786	73	109	179	59	7	10	7,645	2,527	41	61
19	2,437	806	74	110	208	69	15	22	7,779	2,572	17	25
20	NS	-	-	-	557	184	8	12	7,007	2,316	22	33
21	1,961	648	63	94	270	89	8	12	8,270	2,734	18	27
22	1,347	445	51	76	148	49	6	9	6,284	2,077	14	21
23	1,256	415	51	76	204	67	4	6	8,089	2,674	13	19
24	306	101	4	6	129	43	4	6	61	20	2	3
25	NS	-	-	-	371	123	6	9	8,764	2,897	11	16

[a]Sampler positions are numbered in consecutive order from bottom to top. The actual sampling levels, as computed from clinometer data, are given in Table 18.

[b]No sample.

Table 12. Rotorod Recoveries of Green and Yellow FP Expressed in Total Particles Collected and in D/Q Units, Trial B-A2, Phase B, B502.

SAMPLER POSITION[a]	3.2 km BALLOON POSITION				9.7 km BALLOON POSITION				16.1 km BALLOON POSITION			
	GREEN FP		YELLOW FP		GREEN FP		YELLOW FP		GREEN FP		YELLOW FP	
	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)	Total Particles	D/Q Units ($sec/m^2 x10^6$)
1	37	185	4,307	107,675	NS	-	-	-	1,222	6,110	166	4,400
2	240	1,200	4,570	114,250	8,028	40,140	1,371	34,275	50	250	6	150
3	NS[b]	-	-	-	579	2,895	77	1,925	984	4,920	1,451	36,275
4	7,140	35,700	17	425	NS	-	-	-	950	4,750	311	7,775
5	3,588	17,940	4	100	368	1,840	62	1,550	NS	-	-	-
6	689	3,445	0	0	270	1,350	19	475	949	4,745	66	1,650
7	374	1,870	1	25	4,597	22,985	208	5,200	208	1,040	25	625
8	398	1,990	3	75	298	990	0	0	672	3,360	71	1,775
9	0	0	0	0	2	10	0	0	458	2,290	19	475
10	1	5	1	25	1	5	3	75	856	4,280	30	750
11	0	0	0	0	0	0	2	50	88	440	2	50
12	0	0	0	0	2	10	1	25	625	3,125	3	75
13	5	25	0	0	0	0	1	25	1,327	6,635	25	625
14	2	10	2	50	3	15	3	75	60	300	5	125
15	0	0	0	0	1	5	1	25	19	95	0	0
16	0	0	1	25	NS	-	-	-	NS	-	-	-
17	2	10	0	0	0	0	9	225	1	5	0	0
18	0	0	1	25	2	10	0	0	2	10	0	0
19	0	0	0	0	0	0	30	750	0	0	0	0
20	1	5	1	25	6	30	0	0	0	0	0	0
21	NS	-	-	-	1	5	1	25	NS	-	-	-
22	0	0	2	50	1	5	0	0	NS	-	-	-
23	5	25	0	0	0	0	1	25	0	0	0	0
24	NS	-	-	-	5	25	0	0	0	0	0	0
25	0	0	0	0	13	65	4	100	NS	-	-	-

[a]Sampler positions are numbered in consecutive order from bottom to top. The actual sampling levels, as computed from clinometer data, are given in table 18.
[b]No sample.

Table 13. Membrane Filter - Rotorod Sampler Comparisons, Trials B-A1 and B-A2, Phase B, B502.

SAMPLER POSITION[a]		TRIAL A1 GREEN FP Filter Recoveries (part.)	Rotorod Recoveries (part.)	Filter Dosages (part. x sec / liter)	Rotorod Dosages (part. x sec / liter)	Efficiency (%)	YELLOW FP Filter Recoveries (part.)	Rotorod Recoveries (part.)	Filter Dosages (part. x sec / liter)	Rotorod Dosages (part. x sec / liter)	Efficiency (%)
3.2 km Tower	1	1,150	2,778	191.7	67.3	35.1	280	1200	46.7	29.1	62.3
	2	18,958	16,308	3,159.7	394.9	12.5	578	809	96.3	19.6	20.4
	3	27,593	38,120	4,598.8	923.0	20.1	312	661	52.0	16.0	30.8
9.7 km Tower	1	NS[b]	16,309	-	394.9	-	NS	36	-	0.9	-
	2	18,682	57,121	3,113.7	1,383.1	44.4	37	137	6.2	3.3	53.2
	3	21,395	NS	3,565.8	-	-	39	NS	6.5	-	-
16.1 km Tower	1	1,088	2,405	181.3	58.2	32.1	4	19	0.7	0.5	ND[c]
	2	448	2,835	74.7	68.6	91.8	5	10	0.8	0.2	ND
	3	9	NS	1.5	-	-	3	NS	0.5	-	-
		Approximate Medium Efficiency				35	Approximate Medium Efficiency				40

SAMPLER POSITION		TRIAL A2 GREEN FP Filter Recoveries (part.)	Rotorod Recoveries (part.)	Filter Dosages (part. sec / liter)	Rotorod Dosages (part. sec / liter)	Efficiency (%)	YELLOW FP Filter Recoveries (part.)	Rotorod Recoveries (part.)	Filter Dosages (part. sec / liter)	Rotorod Dosages (part. sec / liter)	Efficiency (%)
3.2 km Tower	1	6	0	1.0	0.0	ND	104	320	17.3	7.7	44.5
	2	13	7	2.2	0.2	ND	1,834	280	305.7	6.8	2.2
	3	37	5	6.2	0.1	ND	1,856	453	309.3	11.0	3.6
9.7 km Tower	1	302	42	50.3	1.0	2.0	1,708	278	284.7	6.7	2.4
	2	238	21	39.7	0.5	1.3	1,004	93	167.3	2.3	1.4
	3	788	42	131.3	1.0	0.8	1,424	165	237.3	4.0	1.7
16.1 km Tower	1	600	199	100.0	4.8	4.8	698	275	116.3	6.7	5.8
	2	764	NS	127.3	-	-	854	NS	142.3	-	-
	3	1,484	192	247.3	4.6	1.9	850	98	141.7	2.4	1.7
		Approximate Medium Efficiency				2	Approximate Medium Efficiency				2.5

[a] Tower positions are numbered from lower to higher duplicate sampling position. See paragraph 2.2.3.2 for actual sampling height.
[b] No sample obtained
[c] No determination of efficiency was made.

Table 14. Sequential Recoveries of Green FP for Trial B-A1, Phase B, B502.

SEQUENTIAL "C" 3.2 km		SEQUENTIAL "E" 6.4 km		SEQUENTIAL "G" 9.7 km		SEQUENTIAL "I" 12.9 km		SEQUENTIAL "K" 16.1 km	
Turn On Time	Recoveries[a]	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries
Total	5,284	Total	4,212	Total	44,457	Total	0	Total	148
Z[b] - 14	3	Z + 10	12	Z + 10	2	Z + 30	2	Z + 55	6
Z + 1	4	Z + 25	142	Z + 25	2	Z + 45	74	Z + 70	0
Z + 16	80	Z + 40	10,740	Z + 40	6,964	Z + 60	7	Z + 85	0
Z + 31	1,520	Z + 55	558	Z + 55	14,760	Z + 75	0	Z + 100	50
Z + 46	3,706	Z + 70	43	Z + 70	16,620	Z + 90	0	Z + 115	29
Z + 61	1,340	Z + 85	47	Z + 85	2,600	Z + 105	13	Z + 130	596
Z + 76	69	Z + 100	52	Z + 100	1,294	Z + 120	4	Z + 145	33
Z + 91	10	Z + 115	202	Z + 115	278	Z + 135	648	Z + 160	800
Z + 106	24	Z + 130	M[c]	Z + 130	238	Z + 150	554	Z + 175	1,160
Turn-Off at Z + 196		Turn-Off at Z + 222		Turn-Off at Z + 222		Turn-Off at Z + 248		Turn-Off at Z + 265	

[a]Recoveries are given in terms of total particles contained on the membrane filter.

[b]Z is the time the aircraft began dissemination. Turn-on times are given in minutes plus or minus "Z" time.

[c]Malfunction.

Table 15. Sequential Recoveries of Yellow FP for Trial B-A1, Phase B, B502.

SEQUENTIAL "C" 3.2 km		SEQUENTIAL "E" 6.4 km		SEQUENTIAL "G" 9.7 km		SEQUENTIAL "I" 12.9 km		SEQUENTIAL "K" 16.1 km	
Turn On Time	Recoveries[a]	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries
Total	278	Total	9	Total	126	Total	7	Total	4
Z[b] - 14	7	Z + 10	2	Z + 10	13	Z + 30	3	Z + 55	0
Z + 1	17	Z + 25	3	Z + 25	0	Z + 45	5	Z + 70	0
Z + 16	22	Z + 40	27	Z + 40	22	Z + 60	9	Z + 85	0
Z + 31	7	Z + 55	3	Z + 55	44	Z + 75	158	Z + 100	0
Z + 46	354	Z + 70	0	Z + 70	43	Z + 90	9	Z + 115	3
Z + 61	102	Z + 85	0	Z + 85	7	Z + 105	0	Z + 130	0
Z + 76	1	Z + 100	30	Z + 100	4	Z + 120	7	Z + 145	2
Z + 91	4	Z + 115	0	Z + 115	0	Z + 135	13	Z + 160	3
Z + 106	0	Z + 130	M[c]	Z + 130	6	Z + 150	8	Z + 175	8
Turn-Off at Z + 196		Turn-Off at Z + 222		Turn-Off at Z + 222		Turn-Off at Z + 248		Turn-Off at Z + 265	

[a]Recoveries are given in terms of total particles contained on the membrane filter.

[b]Z is the time the aircraft began dissemination. Turn-on times are given in minutes plus or minus "Z" time.

[c]Malfunction.

Table 16. Sequential Recoveries of Green FP for Trial B-A2, Phase B, B502.

SEQUENTIAL "C" 3.2 km		SEQUENTIAL "E" 6.4 km		SEQUENTIAL "G" 9.7 km		SEQUENTIAL "I" 12.9 km		SEQUENTIAL "K" 16.1 km	
Turn On Time	Recoveries[a]	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries
Total	M[b]	Total	7	Total	196	Total	526	Total	538
Z[c] - 8	M	Z + 9	4	Z + 9	2	Z + 13	14	Z + 20	2
Z + 7	M	Z + 24	4	Z + 24	144	Z + 28	80	Z + 35	46
Z + 22	M	Z + 39	47	Z + 39	41	Z + 43	9	Z + 50	146
Z + 37	M	Z + 54	0	Z + 54	46	Z + 58	136	Z + 65	46
Z + 52	M	Z + 69	0	Z + 69	54	Z + 73	101	Z + 80	22
Z + 67	M	Z + 84	8	Z + 84	12	Z + 88	52	Z + 86	23
Z + 82	M	Z + 99	0	Z + 99	0	Z + 103	30	Z + 110	3
N[d]	-	N	-	N	-	Z + 118	10	Z + 125	2
N	-	N	-	N	-	N	-	Z + 140[e]	0
Turn-Off at Z + 82		Turn-Off at Z + 114		Turn-Off at Z + 114		Turn-Off at Z + 133		Turn-Off at Z + 164	

[a]Recoveries are given in terms of total particles contained on the membrane filter.

[b]Malfunction.

[c]Z is the time the aircraft began dissemination. Turn on times are given in minutes plus or minus "Z" time.

[d]Sampler not operated.

[e]This sequential was possibly not turned off until the samplers were picked up.

Table 17. Sequential Recoveries of Yellow FP for Trial B-A2, Phase B, B502.

SEQUENTIAL "C" 3.2 km		SEQUENTIAL "E" 6.4 km		SEQUENTIAL "G" 9.7 km		SEQUENTIAL "I" 12.9 km		SEQUENTIAL "K" 16.1 km	
Turn On Time	Recoveries[a]	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries	Turn On Time	Recoveries
Total	M[b]	Total	4	Total	1,932	Total	2,076	Total	864
Z[c] - 8	M	Z + 9	1	Z + 9	1	Z + 13	11	Z + 20	0
Z + 7	M	Z + 24	4	Z + 24	1	Z + 28	6	Z + 35	9
Z + 22	M	Z + 39	16	Z + 39	250	Z + 43	5	Z + 50	40
Z + 37	M	Z + 54	0	Z + 54	452	Z + 58	15	Z + 65	8
Z + 52	M	Z + 69	0	Z + 69	612	Z + 73	152	Z + 80	21
Z + 67	M	Z + 84	4	Z + 84	408	Z + 88	700	Z + 86	210
Z + 82	M	Z + 99	0	Z + 99	58	Z + 103	1,178	Z + 110	142
N[d]	-	N	-	N	-	Z + 118	100	Z + 125	61
N	-	N	-	N	-	N	-	Z + 140[e]	2
Turn-Off at Z + 82		Turn-Off at Z + 114		Turn-Off at Z + 114		Turn-Off at Z + 133		Turn-Off at Z + 164	

[a]Recoveries are given in terms of total particles contained on the membrane filter.

[b]Malfunction.

[c]Z is the time the aircraft began dissemination. Turn-on times are given in minutes plus or minus "Z" time.

[d]Sampler not operated.

[e]This sequential was possibly not turned off until the samples were picked up.

Table 18. Estimated Rotorod Sampling Heights, Trials B-A1 and B-A2, Phase B, B502.

SAMPLER NUMBER	ROTOROD SAMPLING HEIGHTS (METERS)			
	TRIAL B-A1			TRIAL B-A2
	3.2 km Position (51° Cable Angle)	9.7 km Position (44° Cable Angle)	16.1 km Position (75° Cable Angle)	All Positions (60° Cable Angle)
1	32	2	40	36
2	40	9	50	45
3	48	17	60	54
4	57	24	71	63
5	65	32	81	73
6	73	39	91	82
7	82	47	101	91
8	90	54	112	100
9	98	62	122	110
10	107	69	133	119
11	115	76	143	128
12	123	84	153	137
13	131	91	163	147
14	140	98	174	156
15	148	106	184	165
16	156	113	194	174
17	165	121	205	183
18	173	128	215	193
19	181	136	225	202
20	190	143	236	211
21	198	150	246	220
22	206	168	256	230
23	214	165	266	239
24	223	173	277	248
25	231	180	287	257

Table 19. Meteorological Conditions Present at the ASG Sampling Tower During Period of Cloud Passage Through Grid Array, Trial B-Al Phase B, B502.

TIME (min)	SAMPLING HEIGHTS																							
	½m	1m		2m			4m		8m		16m			32m			48m		64m			88m		96m
	WS[b]	WS	ΔT[c]	WS	ΔT	Dir[e]	WS	ΔT	WS	ΔT	WS	ΔT	Dir	WS	ΔT	Dir	WS	ΔT	WS	ΔT	Dir	WS	ΔT	Dir
Z[a]	0.4	0.6	-0.1	0.4	0.0	159	I	0.1	1.3	1.9	2.2	3.6	150	4.2	9.1	158	3.9	9.8	4.1	9.8	165	4.5	9.5	181
Z + 5	0.4	0.5	0.0	0.4	0.7	216	I	-0.2	0.9	1.8	1.6	2.2	165	3.7	6.8	164	3.9	9.3	4.2	9.3	175	4.7	9.3	190
Z + 15	0.5	0.6	0.0	0.4	-0.1	160	I	-0.2	0.8	1.2	1.4	1.8	163	3.2	6.4	169	3.0	8.4	3.2	9.1	186	3.7	9.9	203
Z + 30	0.7	0.8	-0.1	0.9	-0.3	200	I	0.3	1.0	1.6	1.3	3.2	131	2.1	8.3	196	1.7	8.1	1.6	8.3	209	2.1	8.3	216
Z + 45	1.1	1.5	-0.4	1.6	-0.5	056	2.3	0.8	2.3	2.6	2.1	3.5	088	1.9	6.3	145	1.0	7.5	0.8	7.5	152	0.6	7.5	182
Z + 60	1.2	1.4	-0.2	1.5	-0.3	065	2.6	0.8	2.7	3.5	2.5	4.3	107	1.9	5.5	143	1.3	7.5	1.1	7.5	125	0.8	7.5	152
Z + 75	1.2	1.5	0.0	1.7	-0.2	061	2.4	1.6	3.1	3.9	3.4	4.5	099	2.4	6.7	095	1.6	7.8	1.2	7.6	113	0.5	7.3	120
Z + 90	1.2	1.5	0.0	1.7	-0.3	060	2.8	0.2	3.1	3.2	4.2	4.2	084	3.8	5.0	085	3.2	5.5	2.8	6.5	108	1.3	8.5	060
Z + 105	1.1	1.2	0.0	1.4	-0.3	080	2.4	0.4	3.3	3.5	3.5	4.9	100	3.2	5.4	095	2.8	5.8	2.7	7.1	132	1.3	8.4	137
Z + 120	1.0	1.3	-0.1	1.3	-0.3	067	2.2	0.4	2.9	2.2	3.7	4.4	095	3.3	4.4	084	2.8	5.6	2.9	7.3	111	2.5	8.5	148
Z + 135	1.3	1.9	-0.1	1.9	-0.2	075	2.9	0.2	3.5	1.5	3.9	3.5	101	3.8	4.1	092	3.4	4.4	3.5	4.8	114	2.1	7.6	141
Z + 150	1.1	1.1	0.0	1.5	-0.2	093	2.5	0.5	3.0	1.8	3.9	3.7	113	4.2	3.9	110	4.0	4.7	4.4	6.5	129	4.1	8.9	137
Z + 165	1.2	1.4	-0.2	1.3	-0.4	107	2.2	0.0	2.8	1.0	4.0	2.2	116	5.9	3.4	112	5.1	4.4	6.0	6.6	123	3.4	7.8	130
Z + 180	1.1	1.4	0.0	1.4	0.0	243	2.0	-0.3	2.1	0.8	2.3	2.1	198	3.3	4.7	185	5.0	5.0	4.2	5.1	128	3.8	5.2	125
Z + 195	0.5	0.5	-0.2	0.5	-0.2	015	I	-0.2	0.6	0.4	0.9	0.9	120	1.5	1.2	087	1.7	2.1	2.8	2.8	099	2.0	3.4	107
Z + 210	0.6	I[d]	0.0	0.6	-0.1	250	I	0.1	0.8	1.0	0.9	1.2	174	1.3	1.7	184	1.3	3.0	1.7	3.7	218	2.3	3.7	127
Z + 225	0.7	I	-0.1	0.9	-0.1	225	I	1.0	1.4	1.8	1.3	2.5	113	1.9	3.2	103	1.5	3.8	2.4	4.0	110	2.9	4.4	125
Z + 240	1.1	I	-0.1	1.4	-0.2	I	2.1	0.6	1.7	1.9	1.9	2.4	182	1.9	2.9	197	1.8	3.0	1.8	3.3	161	2.2	3.5	160
Z + 255	1.3	1.3	-0.1	1.5	0.0	045	I	0.3	1.7	0.7	2.2	1.4	155	2.3	1.9	127	2.5	1.8	I	1.9	100	2.3	4.2	120

[a]Values for Z time are averaged from Z-5 to Z. All other values are averaged over the time interval between that values time and the preceding values time.
[b]Values are in terms of meters per second. WS stands for wind speed.
[c]The temperature gradient is measured from 0.5m to indicated height in F°.
[d]Inoperative.
[e]Wind direction (Dir) values are in degrees.

Table 20. Wind Speeds and Directions Recorded in 15-Minute Intervals at Met Stations 23 North During Passage of Cloud through Grid Array, Trial B-A1, Phase B, B502.

TIME[a] (min)	SAMPLING HEIGHTS							
	0.5m	2m		4m	8m	16m	30m	
	WS[b]	WS	Dir[c]	WS	WS	WS	WS	Dir
Z + 15	0.6	1.9	120	2.1	2.8	4.5	3.4	I[d]
Z + 30	1.0	1.8	100	2.8	3.7	5.1	3.3	I
Z + 45	1.2	1.9	083	2.9	3.4	5.2	4.5	I
Z + 60	1.1	2.0	084	3.0	3.0	4.2	4.9	I
Z + 75	1.2	2.1	094	2.8	3.7	6.1	5.6	I
Z + 90	0.8	1.8	087	2.4	3.1	5.2	5.0	I
Z + 105	0.7	1.7	110	2.1	2.8	5.1	4.6	I
Z + 120	0.8	1.8	095	2.1	2.2	3.1	3.8	I
Z + 135	0.4	0.8	300	0.8	0.6	1.1	1.1	I
Z + 150	0.4	0.6	225	0.8	0.5	0.8	1.0	I
Z + 165	0.4	0.8	185	1.3	1.1	1.1	1.6	I
Z + 180	0.7	1.5	077	2.1	2.0	3.1	2.5	I
Z + 195	0.5	1.1	225	1.0	1.4	2.3	2.5	I
Z + 210	0.5	1.2	248	1.8	1.7	2.9	2.2	I
Z + 225	0.7	1.7	225	2.5	3.0	3.1	2.5	I
Z + 240	0.6	0.8	225	1.0	1.3	2.1	2.4	I
Z + 255	0.8	2.3	090	2.3	2.3	3.3	3.2	I

[a]Time is expressed in minutes after fire time. Each value is an average over the preceeding 15 minutes.

[b]Wind speed (MS) is expressed in meter per second.

[c]Wind direction (Dir) values are in degrees.

[d]Inoperative.

Table 21. Wind Speeds and Directions Recorded at the 16-meter Met Sampling Stations During Estimated Passage of the Cloud through the Grid Array, Trial B-A1, Phase B, B502.

TIME	21 NORTH TOWER				22 NORTH TOWER				24 NORTH TOWER			
	2m Level		16m Level		2m Level		16m Level		2m Level		16m Level	
(min)	WS[a]	Dir[b]	WS	Dir	WS	Dir	WS	Dir	WS	Dir	WS	Dir
Z + 15[c]	0.7	129	1.6	169	0.8	065	I	107	2.6	199	3.0	165
Z + 30	1.3	043	0.9	125	1.0	075	I	097	2.9	115	3.6	137
Z + 45	1.8	006	2.1	101	1.6	088	I	095	3.0	105	3.7	113
Z + 60	1.3	098	2.7	120	1.4	103	I	111	2.1	100	3.4	102
Z + 75	2.0	081	3.3	108	2.1	084	I	088	1.7	088	3.9	095
Z + 90	2.0	071	3.8	089	1.8	090	I	087	2.2	100	3.8	101
Z + 105	1.4	089	3.0	103	1.0	095	I	091	2.2	054	2.7	057
Z + 120	1.8	079	3.4	099	2.3	087	I	095	1.4	084	1.3	095
Z + 135	2.1	092	3.7	105	1.6	115	I	109	0.6	086	0.3	088
Z + 150	1.6	100	3.7	113	1.2	130	I	315	0.7	217	0.3	315
Z + 165	1.5	122	3.0	135	1.6	315	I	151	0.8	235	0.3	250
Z + 180	1.6	280	1.3	335	Calm		I	106	1.1	180	0.6	210
Z + 195	0.6	033	1.0	101	Calm		1.0	132	2.4	160	2.8	155

(Continued)

Table 21. Wind Speeds and Directions Recorded at the 16-meter Met Sampling Stations During Estimated Passage of the Cloud through the Grid Array, Trial B-A1, Phase B, B502.

TIME	21 NORTH TOWER				22 NORTH TOWER				24 NORTH TOWER			
	2m Level		16m Level		2m Level		16m Level		2m Level		16m Level	
(min)	WS[a]	Dir[b]	WS	Dir	WS	Dir	WS	Dir	WS	Dir	WS	Dir
Z + 210	0.8	146	1.0	150	Calm		0.7	170	2.3	192	2.4	184
Z + 225	I[d]	I	1.3	122	Calm		1.6	085	2.5	226	3.8	225
Z + 240	I	I	1.9	170	Calm		1.7	220	2.7	150	2.6	164
Z + 255	I	I	1.7	115	2.5	070	4.4	086	2.2	075	2.3	082

(Concluded)

[a]Wind speed (WS) is expressed in meters per second.

[b]Wind direction (Dir), values are in degrees.

[c]Time is expressed in minutes after fire time. Each value is an average over the preceeding 15 minutes.

[d]Inoperative.

Table 22. Wind Speeds and Directions Recorded at the 8-Meter Met Sampling Stations During Estimated Passage of the Cloud Through the Grid Array, Trial B-A1, Phase B, B502.

TIME	STATION 81		STATION 82		STATION 83		STATION 84	
(min)	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)
Z + 15[a]	2.0	196	2.6	140	2.2	101	1.4	145
Z + 30	2.0	131	2.1	113	3.0	093	1.7	040
Z + 45	2.0	132	3.0	096	3.3	091	2.3	055
Z + 60	1.9	168	3.7	084	3.0	091	1.9	061
Z + 75	1.8	085	3.6	084	3.0	086	2.5	077
Z + 90	1.8	036	3.7	083	3.0	085	2.2	086
Z + 105	3.2	025	2.9	067	2.6	103	2.0	110
Z + 120	I[b]	I	2.6	060	2.3	116	2.5	147
Z + 135	I	I	1.5	342	2.5	129	2.8	154
Z + 150	I	I	1.2	317	0.4	146	3.5	154
Z + 165	I	I	1.1	008	0.3	007	3.0	138
Z + 180	I	I	1.3	057	Calm	Calm	2.8	156
Z + 195	I	I	1.8	017	0.7	280	2.6	165
Z + 210	I	I	1.6	337	0.4	102	1.3	360
Z + 225	I	I	2.1	245	1.0	168	1.3	249
Z + 240	I	I	2.3	146	2.4	080	2.5	090
Z + 255	I	I	3.0	127	3.0	098	2.7	105

[a] Time is expressed in minutes after fire time. Each value is an average over the preceding 15 minutes.

[b] Inoperative.

Table 23. Wind Speeds and Directions Recorded at the 2-Meter Met Sampling Stations During Estimated Passage of the Cloud Through the Grid Array, Trial B-A1, Phase B, B502.

TIME (min)	12 NORTH STATION		13 NORTH STATION	
	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)
Z + 15[a]	2.1	130	2.5	115
Z + 30	1.5	100	2.5	099
Z + 45	2.0	057	2.0	067
Z + 60	2.4	035	2.5	067
Z + 75	1.7	012	3.4	065
Z + 90	2.0	020	2.6	070
Z + 105	1.4	315	2.2	075
Z + 120	0.8	315	2.0	360
Z + 135	Calm	Calm	0.7	070
Z + 150	Calm	Calm	0.7	142
Z + 165	0.5	170	1.0	157
Z + 180	0.7	174	1.1	145
Z + 195	1.1	091	2.0	158
Z + 210	0.6	070	1.9	193
Z + 225	1.7	155	1.3	156
Z + 240	1.3	175	1.6	095
Z + 255	2.0	020	2.5	077

[a]Time is expressed in minutes after fire time. Each value is an average over the preceding 15 minutes.

Table 24. Meteorological Conditions Present at ASG Sampling Tower during Period of Cloud Passage through Grid Array, Trial B-A2, Phase B, B502.

TIME (min)	SAMPLING HEIGHTS																								
	½m	1m		2m			4m		8m		16m			32m			48m			64m			101m		
	WS[b]	WS	ΔT[c]	WS	Dir[e]	ΔT	WS	ΔT	WS	ΔT	WS	Dir	ΔT	WS	Dir	ΔT	WS	Dir	ΔT	WS	Dir	ΔT	WS	Dir	ΔT
Z[a]	1.7	1.9	-0.1	2.2	154	-0.2	I[d]	0.5	3.6	0.4	4.9	148	3.4	7.8	144	11.1	8.3	153	12.2	8.1	174	12.4	8.0	159	12.3
Z + 5	1.6	1.7	-0.1	2.0	154	-0.2	I	0.3	3.2	0.1	4.4	144	2.4	6.8	139	7.8	8.0	151	11.4	8.0	174	12.6	7.7	161	12.8
Z + 15	1.7	1.8	-0.1	2.2	149	-0.2	I	0.2	3.7	0.1	5.2	141	3.2	7.4	134	9.5	7.8	148	12.5	7.6	171	12.9	6.7	162	13.1
Z + 30	1.6	1.7	0.0	2.1	155	-0.1	I	0.7	3.7	0.6	5.6	143	5.2	7.4	135	11.9	7.9	145	14.2	7.6	169	14.4	7.5	152	14.5
Z + 45	2.4	2.5	-0.2	3.0	153	0.1	I	0.7	4.6	0.6	6.1	153	4.3	8.2	140	9.7	9.8	143	10.4	9.3	166	11.3	9.4	153	11.3
Z + 60	2.4	2.6	0.0	3.0	154	0.2	I	0.8	4.6	0.7	6.2	149	3.7	9.0	143	8.1	10.3	138	10.5	9.6	168	10.6	9.7	154	10.5
Z + 75	2.6	2.8	0.0	3.3	155	0.3	I	1.1	4.8	1.0	6.3	148	4.0	8.9	150	7.3	10.6	135	9.5	9.9	172	9.5	9.9	153	9.0
Z + 90	3.2	3.3	0.1	3.7	158	0.4	I	1.1	4.7	0.9	6.6	153	3.5	9.1	150	6.1	10.4	139	7.8	9.9	171	8.1	10.5	155	7.9
Z + 105	2.2	2.4	0.1	2.9	145	0.3	I	1.1	4.2	1.0	6.0	147	3.6	8.1	148	5.6	9.7	134	6.9	9.7	171	7.7	9.5	158	8.1
Z + 120	2.3	2.6	0.2	2.9	135	0.3	I	1.1	4.2	0.8	6.2	148	3.7	8.3	147	6.3	9.2	140	8.2	8.1	173	7.7	8.8	164	7.7
Z + 135	2.4	2.6	0.0	3.1	145	0.2	I	0.9	4.5	0.8	6.2	144	3.8	7.9	145	5.8	9.2	141	7.6	8.9	177	8.6	8.7	162	8.7
Z + 150	1.9	2.0	0.4	2.2	180	0.5	I	1.4	3.1	1.3	4.0	162	2.8	5.6	150	40	8.8	137	6.8	9.9	172	8.6	11.1	154	10.7

[a] Values for "Z" time are averaged from Z-5 to Z. All other values are averaged over the time interval between that values time and the preceding values time.
[b] Values are in terms of meters per second. WS stands for wind speed.
[c] The temperature gradient, ΔT is measured from 0.5 meters to indicated height in F°.
[d] Inoperative.
[e] Wind direction values are in degrees.

Table 25. Wind Speeds and Directions Recorded in 15-Minute Intervals at Met Station 23 North during Passage of Cloud through Grid Array, Trial B-A2, Phase B, B502.

TIME	SAMPLING HEIGHTS												
	0.5m	2m			4m		8m		16m		30m		
(min)	WS[a]	WS	Dir[b]	ΔT	WS	ΔT	WS	ΔT	WS	ΔT	WS	Dir	ΔT
Z + 15[c]	1.1	1.3	178	0.8	1.5	2.8	2.2	4.0	3.0	4.9	5.0	136	6.6
Z + 30	1.3	1.5	193	1.0	1.8	2.5	2.4	3.5	3.0	4.5	4.6	139	6.7
Z + 45	1.2	1.5	191	1.2	2.0	3.5	2.6	4.6	3.0	5.3	4.1	151	6.8
Z + 60	1.3	1.6	135	1.3	1.7	3.3	2.7	5.6	3.3	7.2	4.4	151	9.1
Z + 75	1.2	1.6	108	1.3	1.7	2.9	2.4	4.5	2.7	6.4	4.7	138	8.7
Z + 90	1.7	1.9	155	0.9	I[d]	2.9	3.3	5.6	5.0	8.2	8.1	141	>10.0
Z + 105	I	2.5	176	0.6	I	2.1	4.1	4.2	5.7	7.3	8.2	142	>10.0
Z + 120	I	3.4	160	0.7	I	1.9	5.3	3.4	6.9	5.8	8.9	141	8.5
Z + 135	I	3.0	161	0.7	I	1.9	4.5	3.2	6.4	5.0	8.8	139	8.1
Z + 150	3.4	4.0	156	0.7	I	1.8	6.7	2.9	7.7	4.8	9.1	147	7.6

[a]Wind speed (WS) is expressed in meters per second.

[b]Wind direction (Dir), values are in degrees.

[c]Time is expressed in minutes after fire time. Each value is an average over the preceding 15 minutes.

[d]Inoperative.

Table 26. Wind Speeds and Directions Recorded at the 16-Meter Met Sampling Stations During Estimated Passage of the Cloud through the Grid Array, Trial B-A2, Phase B, B502.

TIME	22 NORTH TOWER				24 NORTH TOWER			
	2m Level		16m Level		2m Level		16m Level	
(min)	WS[a]	Dir[b]	WS	Dir	WS	Dir	WS	Dir
Z + 15[c]	2.0	105	4.2	125	2.8	145	4.8	163
Z + 30	1.9	126	4.7	126	2.7	137	4.4	155
Z + 45	2.5	156	5.7	142	2.9	151	4.9	160
Z + 60	3.6	145	6.3	140	3.3	120	5.2	135
Z + 75	3.3	146	5.8	141	2.3	110	4.1	120
Z + 90	3.3	152	6.1	147	1.8	110	3.4	125
Z + 105	3.1	145	5.7	141	2.1	124	3.4	146
Z + 120	3.3	158	4.1	150	2.1	114	3.9	140
Z + 135	2.4	180	4.3	170	2.5	125	5.5	148
Z + 150	2.2	172	5.6	162	3.8	132	7.0	147

[a]Wind speed (WS) is expressed in meters per second.

[b]Wind direction (Dir), values are expressed in degrees.

[c]Time is expressed in minutes after fire time. Each value is an average over the preceding 15 minutes.

Table 27. Wind Speeds and Directions Recorded at the 8-Meter Met Sampling Stations During Estimated Passage of the Cloud Through the Grid Array, Trial B-A2, Phase B, B502.

TIME	STATION 81		STATION 82		STATION 83		STATION 84	
(min)	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)	Wind Speed (meters/sec)	Wind Direction (°)
Z + 15[a]	2.9	142	3.0	205	4.0	135	2.0	109
Z + 30	3.4	135	3.4	168	3.4	130	2.1	104
Z + 45	3.8	138	3.4	170	3.8	121	2.8	110
Z + 60	4.9	122	3.0	199	3.0	115	3.8	138
Z + 75	5.5	125	2.7	193	3.0	129	3.9	137
Z + 90	5.1	120	3.3	205	4.0	136	3.6	137
Z + 105	3.5	I[b]	3.5	192	5.0	150	3.8	134
Z + 120	1.6	I	3.0	187	4.9	149	3.3	131
Z + 135	2.0	I	3.0	155	4.9	145	3.2	130
Z + 150	2.3	I	4.3	142	4.5	145	3.5	127

[a]Time is expressed in minuted after dissemination time. Each value is an average over the preceding 15 minutes.

[b]Inoperative.

Table 28. Wind Speeds and Directions Recorded at the 2-Meter Met Sampling Stations During Estimated Passage of the Cloud through the Grid Array, Trial B-A2, Phase B, B502.

TIME	12 NORTH STATION		13 NORTH STATION		21 NORTH STATION	
(min)	Wind Speed (meters/sec)	Direction (°)	Wind Speed (meters/sec)	Direction (°)	Wind Speed (meters/sec)	Direction (°)
Z + 15[a]	1.8	150	2.2	145	5.4	120
Z + 30	2.1	130	2.0	171	5.9	120
Z + 45	2.1	125	2.1	169	6.4	125
Z + 60	2.4	117	2.2	127	6.5	127
Z + 75	2.5	121	1.9	120	6.6	127
Z + 90	1.9	120	2.6	103	6.5	130
Z + 105	2.2	140	2.9	109	6.3	124
Z + 120	3.0	154	2.2	116	6.4	118
Z + 135	3.3	147	2.7	130	6.5	122
Z + 150	2.8	133	3.9	114	4.3	134

[a]Time is expressed in minutes after dissemination time. Each value is an average over the preceding 15 minutes.

APPENDIX

XIII

GCA TECHNICAL REPORT NO. 66-13-G

SURVEY OF THE ELEVATED LINE SOURCE

TECHNICAL REPORT

by

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DIGEST

Current procedures for predicting ground-level dosage patterns associated with elevated line sources are reviewed with respect to existing theoretical and empirical knowledge. Analysis of field measurements made during the Dallas Tower trials and the B 502 program at Dugway Proving Ground reveals important meteorological restrictions on the operational employment of the elevated line source and defines the conditions under which this technique is most likely to produce satisfactory results.

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SUMMARY

Current procedures for modeling elevated line-source releases have been examined with respect to existing knowledge of low-level atmospheric structure and measured dosage patterns. Comparisons of existing prediction techniques show the principal differences to be in the method used to specify the rate of vertical expansion of the cloud, and in the extent to which source dimensions, multiple reflections, and edge effects have been incorporated into the basic Gaussian model.

An examination of available field data and an intensive analysis of measurements made during the Dallas Tower trials and the B 502 series at Dugway Proving Ground clearly indicates that the elevated line-source technique is most effective when the releases are made at heights of the order of 100 meters above relatively smooth terrain in the presence of moderate or strong wind speeds and near-neutral thermal stratification. Requisite atmospheric dispersal and transport mechanisms depend upon a high degree of coupling between the air flow at release height and the flow at ground level. This precludes the presence of moderate or strong temperature inversions located either near ground level or at any height intermediate between the release height and the ground. A sufficient degree of coupling is indicated by a mean wind speed near the ground of at least 3 meters per second and a wind speed at the effective release height of at least 10 meters per second. Also, the turbulent intensity of the vertical component of the wind velocity at release height must exceed 0.01. Both the Dallas Tower trials and the B 502 series confirm that little or no material reaches ground level within 40 or 50 kilometers of aerial releases made above strong temperature inversions. It is unlikely that penetration of such an inversion can be accomplished other than by very low releases (less than 50 meters) aided by aircraft wake turbulence.

SECTION 1

INTRODUCTION

The use of elevated line source releases in BC operations rests on the premise that the released material will be diffused vertically downward to ground level and transported to the target area in an orderly and predictable manner by the low-level wind field. The effectiveness of the low-level wind in transporting and diffusing material released at some height above the ground to a ground-level target depends upon two closely related factors: the depth of the mixing layer and the degree of coupling between the wind pattern at the effective release height and that near ground level. During unstable stratification, the depth of the mixing layer is fixed by the upper limits of convective processes; during stable stratification, the depth of this layer is determined by the height to which the mechanical turbulence arising from airflow over uneven ground and other roughness elements can penetrate. Over land surfaces in fair weather, the depth of the surface layer shows a diurnal variation ranging from 1 or more kilometers in the presence of free convection to perhaps 10 meters or less in the presence of strong radiational surface temperature inversions. Both the depth of the surface layer and the degree of coupling between the flow at release height and the flow near ground level are highly correlated with the vertical gradients of wind speed and temperature.

Frequently, processes other than simple wind transport and turbulence influence the ground-level distribution of the released material. These processes include terrain-induced air motions that may be enhanced by atmospheric dynamics; occasional overturnings of large masses of air due to transient effects associated with the formation and breakdown of nocturnal low-level temperature inversions; surface drainage or up-slope terrain circulations; and circulations associated with large convective cells.

When expressed in mathematical terms, diffusion models are essentially probabilistic mass continuity equations defining the spatial and temporal distribution of material downwind from the point of release under steady state conditions. Expressions of this type must specify four basic features: the mean horizontal wind vector defining the material transport; the form of crosswind and vertical distributions; the crosswind and

vertical dimensions of the plume as functions of downwind distance; and losses of material through decay or removal processes. The probabilistic nature of model equations, although not usually explicitly stated, reflects the inherent variability of the atmospheric processes and has the following significance: the predicted value given by the equation represents the average result to be expected from a large number of individual trials conducted under nearly identical conditions. Predicted values of diffusion parameters obtained from diffusion models thus represent the central or mean values of probability distributions. A prime objective in model validation is to establish the bounds or fiducial limits of these distributions.

The prediction of dispersal patterns for an environment in which the spectrum of atmospheric motion is essentially continuous poses many difficulties. The prediction of dispersal patterns for an environment in which mesoscale circulations, or other processes highly dependent on space and time, are present is clearly beyond the limits of existing knowledge and capabilities. An investigation of the basic mechanisms of mesoscale circulations, with emphasis on applications to dispersal prediction, is in process under Contract No. DA-42-007-AMC-120(R) and the results to date are reported by Barr and Tweedy (1967).

Section 2 of this report contains a review of current procedures for modeling the elevated line source. Four field measurement programs in which elevated line source releases were made are summarized in Section 3. An evaluation of current prediction procedures principally based on the measurements made during two of these programs is presented in Sections 4 and 5. General conclusions based on this review of the elevated line source problem are found in Section 6.

SECTION 2

ELEVATED LINE-SOURCE MODELING TECHNIQUES

Most practical line source models in current use are based on the Gaussian form of Sutton's equations. As formulated by Milly (1958) in ORG-17, the expression for ground level dosage becomes

$$D(x) = \frac{2Q}{\sqrt{2\pi}\,\sigma_z\,(x_1)\,\bar{u}\left(\frac{x}{x_1}\right)^{\beta}}\ \exp\left[-\frac{h^2}{2\sigma_z^2\,(x_1)\left(\frac{x}{x_1}\right)^{2\beta}}\right] \qquad (2\text{-}1)$$

where $D(x)$ = ground level dosage
Q = source strength
$\sigma_z\,(x_1)$ = standard deviation of vertical dosage distribution at some reference distance x_1 downwind from the release line
$\bar{u}$ = mean wind speed
x = downwind distance
β = diffusion parameter related to thermal stratification
and h = release height.

Equation (2-1) is equivalent to Sutton's expression

$$D(x) = \frac{2Q}{\sqrt{2\pi}\,C_z\,\bar{u}\,x^{(2-n)/2}}\ \exp\left[-\frac{h^2}{C_z^2\,x^{2-n}}\right], \qquad (2\text{-}2)$$

as may be seen by application of the transformations

$$\beta = 1 - \frac{n}{2} \qquad (2\text{-}3)$$

and

$$2\sigma_z^2\,(x_1)\left(\frac{x}{x_1}\right)^{2\beta} = C_z^2\,x^{2-n} \qquad (2\text{-}4)$$

Here C_z is a generalized diffusion coefficient related to the intensity of turbulence, and n is, at least in principle, determined from the wind profile according to an equation of the form

$$\bar{u}(z) = \bar{u}_1 \left(\frac{z}{z_1} \right)^{n/(2-n)} \quad . \tag{2-5}$$

Maximization of Equation (2-1) yields the expression

$$D_{max} = \frac{Q}{\bar{u}h} \sqrt{2/\pi e} = 0.485 \frac{Q}{\bar{u}h} \quad , \tag{2-6}$$

which is independent of β and $\sigma_z(x_1)$. It can be seen that the maximum ground-level dosage predicted by the Gaussian model depends only on Q, $\bar{u}$, and h. On the other hand, the downwind distance x_{max} at which D_{max} occurs is found to be

$$x_{max} = \left[\frac{h}{\sigma_z(x_1)} \right]^{1/\beta} x_1 \quad . \tag{2-7}$$

The distance x_{max} thus depends on β, $\sigma_z(x_1)$, x_1, and h and is independent of Q and $\bar{u}$.

The following sections contain summary descriptions of recent approaches to the modeling of dispersal patterns from an elevated line source. For the most part, these approaches differ only in the method used to specify the rate of vertical expansion of the cloud.

2.1 PALMER AND CRAW (1962)

Palmer and Craw prepared graphs of D/Q versus downwind distance using Equations (2-1) and (2-2) and procedures suggested earlier by Barad and Hilst (1951). Graphs are presented for various combinations of release height, wind speed, and the diffusion parameters q and n. In addition, the effects of biological decay are taken into consideration by multiplying Equations (2-1) and (2-2) by the exponential factor exp(-kt), where time t is given by $x/\bar{u}$, and k is the decay constant. The ranges of the various input parameters used are given in Table 2-1.

2.2 ELLIOTT AND BARAD (1964)

Elliott and Barad also used Equation (2-2) to construct graphs of ground-level dosage for operational use in predicting diffusion patterns downwind from line sources. Graphs are presented for various heights of release, wind speeds, and thermal stratification. Stability classifications are defined by the stability ratio SR, given by the ratio of the

TABLE 2-1

PARAMETERS USED BY PALMER AND CRAW

Stratification:	n	β
Near Neutral	0.25	0.875
Slight Inversion	0.30	0.85
Moderate Inversion	0.33	0.83
Strong Inversion	0.40	0.80
Release Height, h: 0 to 1000 feet		
Mean Wind Speed, $\bar{u}$: 5 to 30 miles per hour		
Decay Rate, k: 0 to 0.2 per minute		

TABLE 2-2

PARAMETERS USED BY ELLIOTT AND BARAD

Stratification	Range of SR	C_z	n	β
Very Unstable	< -0.45	0.002	-1.20	1.60
Moderately Unstable	-0.45 to -0.20	0.02	-0.40	1.20
Neutral	-0.20 to 0.20	0.07	0.10	0.95
Moderately Stable	0.20 to 0.45	0.07	0.20	0.90
Very Stable	> 0.45	0.07	0.30	0.85

temperature difference in centigrade degrees between 4 meters and 0.5 meters to the square of the 2-meter wind speed in meters per second. Each stability class is associated with values of C_z and n determined from an analysis of the Prairie Grass data (Haugen, Barad, and Antanaitis, 1961). Table 2-2 presents the stability classifications and the diffusion parameters that were used. Because of vertical inhomogeneity in the structure of turbulence, direct application of parameters determined from diffusion measurements from continuous point-source emissions near the ground (as at Prairie Grass) to elevated sources appears inappropriate. It is likely that the effective vertical expansion rates will exceed those implied in Table 2-2 during unstable regimes and will be considerably smaller during stable regimes. Comparison of the β values presented in Tables 2-1 and 2-2 shows the values used by Elliott and Barad to be consistently greater than those of Palmer and Craw during near-neutral and stable stratifications.

2.3 VAUGHAN AND McMULLEN (1963)

Vaughan and McMullen have treated the vertical expansion of a gas or aerosol cloud by assuming that heat and matter are diffused by identical mechanisms. Except for near-neutral conditions their calculations of the rate of vertical diffusion of matter are based on determinations of the vertical heat flux. In the absence of direct measurements, estimates of the heat flux are obtained from observations of the rates of temperature change within the surface layer. The effect of advection is eliminated by assuming that the advective temperature change is constant in time and independent of height. An average value of K_H for the appropriate layer is then obtained from the heat flux estimates and the potential temperature profile. In near-neutral stratification the diffusivities for heat and momentum are assumed equal near the ground, and an empirical method based on the Prairie Grass measurements is used to determine K_H from the wind speed at a height equal to 40 times the roughness parameter z_o. Predicted dosages are calculated from the generalized Gaussian model after the introduction of a parameter S defined as $\bar{u}h^2/4Kx$, in which K is the mean vertical diffusivity.

Discussions of the role of the K theory in atmospheric diffusion, and its limitations, are available in Sutton (1953) and Hinze (1959). The relationships between the diffusivities of momentum, heat, and matter have not yet been firmly established empirically. Existing measurements of the diffusivities for heat K_H and momentum K_M indicate the following relationships: $K_H > K_M$ during thermal instability; $K_H = K_M$ in near-neutral stratification; and $K_H < K_M$ in stable stratifications (Cramer and Record, 1953; Swinbank, 1955, 1964; Lettau and Davidson, 1957; Lumley and Panofsky, 1964). These data also indicate that the ratio K_H/K_M increases with height in the presence of thermal instability. Vertical diffusion from elevated sources frequently takes place throughout a layer several hundred feet in depth, and releases may also be made in the presence of strong surface temperature inversions. The assumption

that the advective temperature change remains constant with height under these conditions is probably invalid.

2.4 SMITH AND HAY (1961)

Smith and Hay, working from the statistical theory of turbulence, derived an expression for the rate of vertical expansion of a cluster of particles under the assumptions of isotropy, homogeneity, a Gaussian particle distribution, and, perhaps most importantly, a constant ratio β between the Eulerian and Lagrangian scales, as suggested by Pasquill (1957).

The complicated expression derived for the expansion of the cluster with travel distance proved to be nearly linear over the range of the expansion during which the standard deviation of the cluster distribution σ is within an order of magnitude of the scale length of the turbulence. For this part of the cluster's history, Smith and Hay obtained the approximation:

$$\frac{d\sigma}{dx} = \frac{2}{3} \beta i^2 \quad , \qquad (2\text{-}8)$$

where i is the intensity of turbulence. Using data from elevated line releases and ground-level cluster releases sampled at downwind distances ranging from less than 100 meters to 15 kilometers, they found an optimum value of the scaling ratio β of 4.5. Inserting this values of β into Equation (2-8) gives

$$\frac{d\sigma}{dx} = 3i^2 \; . \qquad (2\text{-}9)$$

Several investigators have applied this formula to elevated line releases. For this application Equation (2-9) becomes

$$\frac{d\sigma_z}{dx} = 3i_z^2 \qquad (2\text{-}9a)$$

In applying Equation (2-9a) to the Dallas Tower line source measurements, MacCready, Smith and Wolf (1961) used an "effective" turbulent intensity i_e to compensate for the vertical gradient of turbulence between the release height and ground level. Measured values of the intensity were weighted according to the estimated residence time of the cloud within selected layers to obtain a value representative of turbulent conditions encountered between release height and the ground. The success of this technique in predicting ground-level dosages is discussed in Section 4.

2.5 GCA MODEL

The GCA model is based on generalized dosage prediction techniques developed by Cramer et al (1964) in work for the Meteorology Division at Dugway Proving Ground under Contract Nos. DA-42-007-CML-552 and DA-42-007-AMC-120(R). The basic model equation is the dosage form of the Gaussian plume equation for an elevated line source given by the following expression:

$$D\{x,y,z;\tau,x_z,\sigma_{z_o},h,H,L\} = \frac{Q}{\sqrt{2\pi}\,\bar{u}\,\sigma_z\{x;x_z,\sigma_{z_o}\}} \left\{\exp\left[-\frac{(h-z)^2}{2\sigma_z^2\{x;x_z,\sigma_{z_o}\}}\right]\right.$$

$$+ \exp\left[-\frac{(h+z)^2}{2\sigma_z^2\{x;x_z,\sigma_{z_o}\}}\right] + \sum_{n=1}^{\infty}\left[\exp\left(-\frac{(2nH-h-z)^2}{2\sigma_z^2\{x;x_z,\sigma_{z_o}\}}\right)\right.$$

$$+ \exp\left(-\frac{(2nH-h+z)^2}{2\sigma_z^2\{x;x_z,\sigma_{z_o}\}}\right) + \exp\left(-\frac{(2nH+h-z)^2}{2\sigma_z^2\{x;x_z,\sigma_{z_o}\}}\right)$$

$$\left.\left.+ \exp\left(-\frac{(2nH+h+z)^2}{2\sigma_z^2\{x;x_z,\sigma_{z_o}\}}\right)\right]\right\} \left\{\operatorname{erf}\left[\frac{L/2+y}{\sqrt{2}\,\sigma_y\{x;\tau\}}\right]\right.$$

$$\left.+ \operatorname{erf}\left[\frac{L/2-y}{\sqrt{2}\,\sigma_y\{x;\tau\}}\right]\right\} \qquad (2\text{-}10)$$

The symbols in the above equation are defined as follows:

x = distance downwind from release point

y = crosswind distance from plume axis

z = height above ground

τ = source function time or time duration of release

x_y = crosswind virtual distance

x_z = vertical virtual distance

L = length of release line

σ_{z_o} = initial vertical plume dimension

σ_y = standard deviation of the crosswind distribution

σ_z = standard deviation of the vertical distribution

h = effective release height

H = depth of surface mixing layer defined as height above ground of the base of a capping temperature inversion

Q = source strength

$\bar{u}$ = mean wind speed at height z.

The summation term on the right side of Equation (2-10) takes into account the multiple reflection of the cloud between the base of a capping temperature inversion at height H and the ground (Milly, 1958; Bierly and Hewson, 1962). The error function term provides a means for adjusting for edge effects due to the finite crosswind extent of release lines.

The form of the crosswind and vertical distributions at various downwind distances is in principle described by equations similar to the spectrum form of G.I. Taylor's (1938) formula for the mean-square separation of particle pairs. In symbols,

$$\sigma_y^2 (x) = \frac{\sigma_v^2}{\bar{u}^2} x^2 \int_0^\infty F_v(n) \left[\frac{\sin \pi n\, x/\bar{u}}{\pi n x/\bar{u}} \right]^2 dn \qquad (2\text{-}11)$$

and

$$\sigma_z^2 (x) = \frac{\sigma_w^2}{\bar{u}^2} x^2 \int_0^\infty F_w(n) \left[\frac{\sin \pi n\, x/\bar{u}}{\pi n x/\bar{u}} \right]^2 dn \qquad (2\text{-}12)$$

where

σ_y = the standard deviation of the crosswind distribution

σ_z = the standard deviation of the vertical distribution

$\sigma_v/\bar{u}$ = the turbulent intensity of the lateral wind-velocity component

$\sigma_w/\bar{u}$ = the turbulent intensity of the vertical wind-velocity component

x = downwind distance from release point

F_v, F_w = the normalized power spectrum functions of the lateral and vertical wind-velocity components respectively

$\bar{u}$ = the mean wind velocity

n = frequency.

For practical applications, Equations (2-11) and (2-12) are approximated by simple power-law expressions of the general form

$$\sigma_y \{x,\tau\} = \overline{\sigma'_A}\, x_1 \left(\frac{x}{x_1}\right)^{\alpha} \tag{2-13}$$

and

$$\sigma_z \{x\} = \sigma'_E\, x_1 \left(\frac{x}{x_1}\right)^{\beta} \tag{2-14}$$

where

σ'_A = standard deviation of azimuth wind direction in radians

σ'_E = standard deviation of elevation angle in radians

τ = source release time

x_1 = a reference distance

α,β = empirical constants. Typical values of the power-law exponent α range from about 0.8 to 1.0, while β varies from about 0.5 in stable stratification to 1.0 for near-neutral stratification and larger than 1.0 for unstable stratification,

and the overbar indicates a time average.

Equation (2-13) is adjusted for the source function time τ through a semi-empirical one-fifth power-law relationship defined by the expression

$$\sigma'_A \{\tau\} = \sigma'_A \{\tau_o\} \left[\frac{\tau}{\tau_o}\right]^{1/5} , \tag{2-15}$$

where τ_o is the length of record or averaging time required to obtain a satisfactory estimate of σ'_A from field observations. The predictor σ'_E is not significantly dependent on source release time because of the concentration of energy of the vertical component of wind velocity in small eddy sizes.

The basic model equation is adjusted for initial source dimensions through the use of a virtual distance x_z, defined by the expression

$$x_z = \sigma_{z_o} / \sigma'_E \ . \tag{2-16}$$

The virtual distance x_z is substituted for the reference distance x_1 in the working expressions for vertical plume expansion given by Equation (2-14) which then becomes

$$\sigma_z (x) = \sigma_{z_o} \left(\frac{x}{x_z} \right)^{\beta} \quad . \qquad (2\text{-}17)$$

2.5.1 Nondimensional Ground-Level Dosage Profiles. The ground-level dosage profiles associated with the GCA elevated line-source model are defined by a simple family of curves if dosage is normalized by its maximum value and distance is normalized by the distance at which the maximum dosage occurs. These nondimensional profiles are shown in Figure 2-1, each curve in the figure being identified with a specific value of the power-law exponent β. The ordinate D/D_{max} and abscissa x/x_{max} in Figure 2-1 are related by the expression

$$D/D_{max} = \sqrt{e} \left(\frac{x}{x_{max}} \right)^{-\beta} \exp \left[- \frac{1}{2} \left(\frac{x}{x_{max}} \right)^{-2\beta} \right] \quad . \qquad (2\text{-}18)$$

2.5.2 Adjustment for Aircraft Wake Effects. Field experiments have indicated that the initial vertical cloud dimensions associated with aircraft line-source releases are enhanced by the wake-vortex field of the aircraft. The expected vertical dimension z_w of the wake-vortex field is given by the expression $z_w = 1.33b$, where b is the wingspan of the aircraft. Smith and MacCready (1963) have obtained a close correspondence between calculated and measured values of vertical wake dimension for various aircraft types using this expression. The calculated values range from about 50 meters for the C 119 aircraft to 10 meters for the A-4D. Adjustment for the initial source dimensions may be made through Equations (2-16) and (2-17) as explained above.

2.6 SUMMARY COMPARISON OF MODEL PREDICTION FORMULAS

Formulas for describing basic features of the ground-level dosage patterns predicted by four of the elevated line source models discussed earlier are summarized in Table 2-3. Entries in the table are the mathematical expressions for the ground-level dosage profile $D(x,o)$, the maximum ground-level dosage D_{max}, and the distance x_{max} from the release line to the point at which D_{max} is found. As noted previously, all four of the models exhibit identical expressions for D_{max}, and these are in turn identical with Sutton's formula for the maximum ground-level dosage from an elevated line source. Differences in the formulas for $D(x,o)$ and x_{max} reflect the use of different meteorological predictors to describe the vertical expansion of the cloud. The Metronics model formulas differ most due to the use of the diffusivity coefficient for turbulent heat transfer as the prime meteorological predictor. The ORG-17 and GCA model formulas for $D(x,o)$ and x_{max} are almost identical in form. Provided that the values selected for β are approximately equal, the ground-level dosage profiles for the GCA and ORG-17 models should agree quite closely.

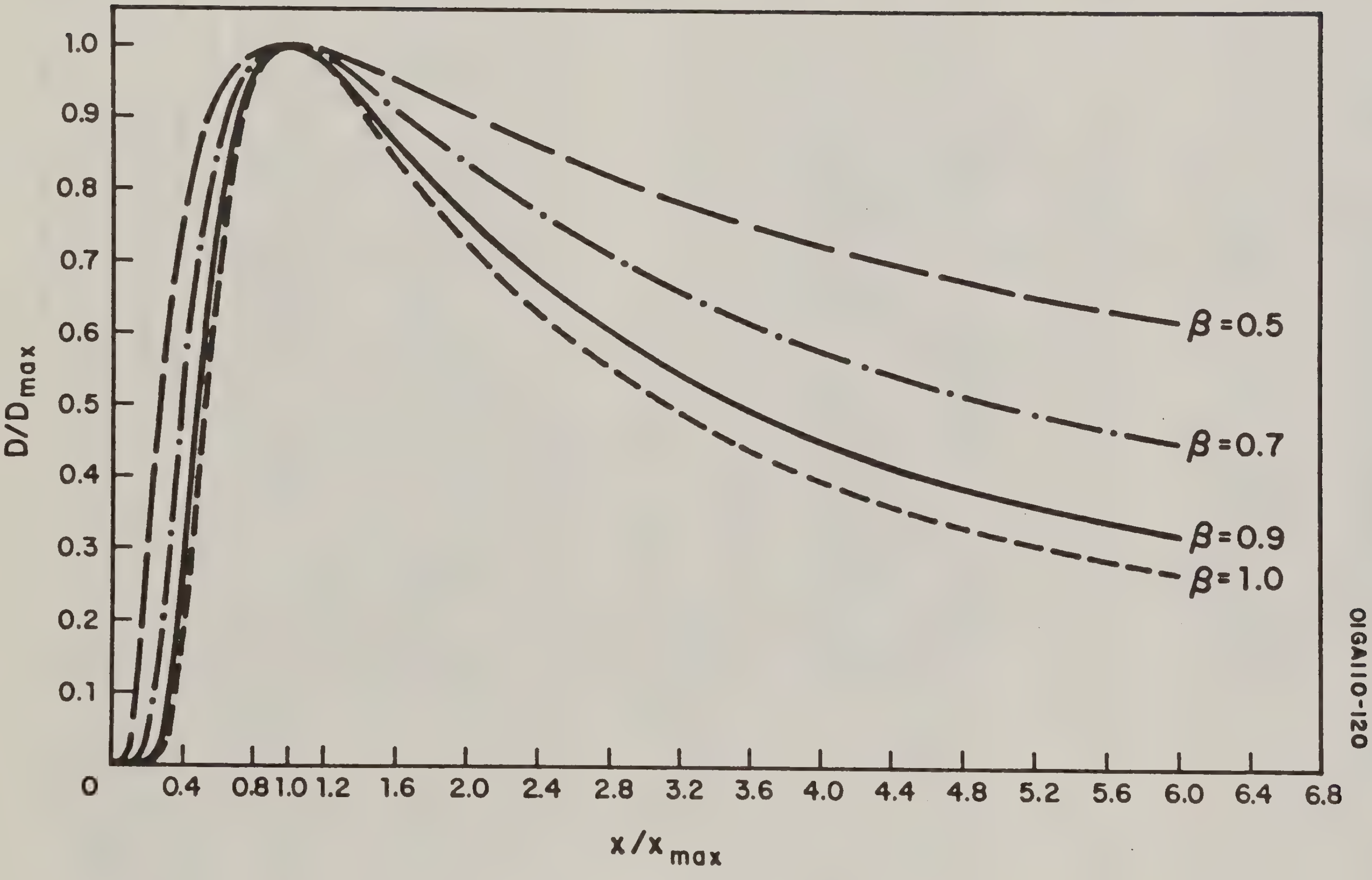

Figure 2-1. Nondimensional ground-level dosage profiles for selected values of the power-law exponent β.

TABLE 2-3

SUMMARY OF ELEVATED LINE SOURCE MODELS

Model	D{x,o}	D_{max}	x_{max}
MRI	$\frac{2Q}{\sqrt{2\pi}\ \bar{u}\ (3i^2x)} \exp - \frac{h^2}{2(3i^3x)^2}$	$\frac{2Q}{\sqrt{2\pi e}\ \bar{u}\ h}$	$\frac{h}{3i^2}$
Metronics	$\frac{2Q[\bar{u}\ h^2/4K_H x]^{1/2}}{\sqrt{\pi}\ \bar{u}\ h} \exp - \frac{\bar{u}\ h^2}{4K_H x}$	$\frac{2Q}{\sqrt{2\pi e}\ \bar{u}\ h}$	$\frac{\bar{u}\ h^2}{2K_H}$
ORG-17	$\frac{2Q}{\sqrt{2\pi}\ \bar{u}\ \sigma_z\{x_1\} \left[\frac{x}{x_1}\right]^{\beta}} \exp - \frac{h^2}{2\sigma_z^2\{x_1\} \left[\frac{x}{x_1}\right]^{2\beta}}$	$\frac{2Q}{\sqrt{2\pi e}\ \bar{u}\ h}$	$\left[\frac{h}{\sigma_z\{x_1\}}\right]^{1/\beta} x_1$
GCA*	$\frac{2Q}{\sqrt{2\pi}\ \bar{u}\ \sigma_E'\ x_1 \left[\frac{x}{x_1}\right]^{\beta}} \exp - \frac{h^2}{2[\sigma_E'\ x_1]^2 \left[\frac{x}{x_1}\right]^{2\beta}}$	$\frac{2Q}{\sqrt{2\pi e}\ \bar{u}\ h}$	$\left[\frac{h}{\sigma_E'\ x_1}\right]^{1/\beta} x_1$

*The quantity x_1 is a reference distance.

SECTION 3

SUMMARY OF FIELD PROGRAMS

Recent field programs using elevated line releases are summarized briefly in the subsections that follow. Details of sampling method, meteorological support data, instrumentation, and environment are presented in Table 3-1. Measurements made in the Dallas Tower and B 502 field programs are analyzed in detail in Sections 4 and 5.

3.1 PROJECT WINDSOC

A series of thirteen trials were conducted by Dugway Proving Ground in central Texas during the fall and winter of 1959. Ground-level dosage patterns over the 125-mile square test grid showed considerable variability. An attempt was made by Meteorology Research, Inc. to explain the variability in terms of meteorological parameters and terrain irregularities, but no diffusion model was applied (Smith and Wolf, 1961).

3.2 DALLAS TOWER STUDIES

Thirty-seven trials were conducted near Dallas, Texas by Meteorology Research, Inc. under contract to Dugway Proving Ground (MacCready, Smith, and Wolf, 1961). Detailed meteorological data for the series were collected from the surface to 320 meters with instruments mounted on the Cedar Hill (Dallas) Tower. Dosage sampling was carried out by sequential filter samplers located at various levels on the tower and by rotorod samplers located at ground level at intervals of 1.6 kilometers downwind from the release line to a distance of about 48 kilometers downwind. A crosswind line of rotorod samplers was operated near the end of the alongwind sampling line during twelve of the trials. A detailed re-analysis of these data is presented in Section 4.

3.3 VARIETY-OF-TERRAIN TRIALS

A total of thirty six trials were conducted to test available prediction techniques at locations with widely different terrain characteristics. These trials, also carried out by Meteorology Research, Inc. for Dugway Proving Ground, were divided among sites in Oklahoma, Washington, Nevada, and near Corpus Christi, Texas. Sampling was essentially restricted to ground-level dosages. In all but the Oklahoma trials, which were made

TABLE 3-1

SUMMARY OF ELEVATED LINE SOURCE EXPERIMENTS

	No. Trials	Terrain and Vegetation	Tracer	Release Height (m)	Max. Downwind Sampling Distance (km)	Ground-Level Sampling	Vertical Sampling	Measured Meteorological Parameters	Instrumentation
Windsoc	13	Rolling	FP	180 to 400	160	Sequential millipore filters; rotorods	Balloon-borne millipore filters; aircraft	Sfc winds Upper winds Sfc temp Temp profiles	AN/GMQ-1 Pibals
Dallas Tower	37	Rolling Woodlot	FP	120 to 300	48	Rotorods	Tower mounted millipore filters	Turbc profiles Wind profile 320 m Temp profiles	MRI Bivanes Bendix-Friez Aerovanes Aspirated Cu-Constantan Thermocouples
Oklahoma	9	Rolling	FP	150	50	Rotorods			
Washington	9	Low Mtns. Sparse Veg.	FP	370	45	Rotorods		Turbc (to 30 m) Turbc aloft Wind	MRI Bivanes MRI Turbc Meter (Aircraft) 3-cup Anemometer
Corpus Christi	9	Shoreline Woodlot	FP	150 to 300	40	Rotorods		Temp profiles ($\leq$ 30 m) Wind aloft	Shielded Thermistors Pibals
Nevada	8	Mountain Sparse Veg.	FP	430	40	Rotorods			
Dugway	14	Low Mtns. Sparse Veg.	FP	76 to 120	24	Membrane filters	Balloon-borne rotorods	Temp profiles Wind profiles Turbc profiles Temp profiles ~ 365 m Upper winds	Cu-Constantan Thermocouples Beckman-Whitley Vane Gelman Bivanes Planesonde Pibals

over rolling terrain, observed dosages proved to be very different from those predicted using the model of MacCready, Smith and Wolf described in Section 2.4. In explanation of the observed dosage patterns, Smith and Wolf (1963) presented subjective appraisals of the meteorological and topographical causative factors.

In the Corpus Christi trials, the releases were made over water during periods of onshore winds; ground-level dosages were measured from the shoreline to a maximum distance of 40 kilometers inland. At the shoreline, the flow was subjected to discontinuities in both roughness and thermal stability. Turbulence measurements were made from the release aircraft and on a 30-meter tower located at the shoreline. These measurements are therefore representative of the low-turbulence marine air into which the cloud was released rather than the over-land regime in which much of the growth of the cloud took place. However, the occurrence of the high dosage values which were quite consistently observed near the shoreline appears to be unexplained by reasonable adjustments in turbulent intensities. The possible existence of helical circulations near the shoreline was suggested as a mechanism for the rapid downward transfer of the tracer.

3.4 B 502 SERIES

Fourteen trials were carried out at Dugway Proving Ground, Utah, and analyzed by Metronics Associates, Inc., (Vaughan and McMullen, 1963; Vaughan, 1965). Dosage measurements were made with both ground-level and vertical sampling arrays. The ground-level network comprised a line of volumetric air samplers extending from the release line to a maximum downwind distance of about 24 kilometers. Rotorod samplers mounted on cables suspended from balloons provided measurements in the vertical to a height of approximately 230 meters. Samplers were also positioned at intervals along one 90-meter tower and four 30-meter towers. One of the principal problems encountered during these trials was the presence of mesoscale circulations which produced irregular cloud trajectories. In addition to supplying needed data on dispersion rates, the vertical sampling array furnished quantitative measurements of the initial downward displacement of the cloud due to aircraft wake vortex effects. An evaluation of the B 502 measurements is presented in Section 5.

SECTION 4

ANALYSIS OF DALLAS TOWER FIELD TRIALS

A detailed description of the experimental procedures and other features of the Dallas Tower Field Trials has been given by MacCready, et al (1961). The entire series of diffusion trials consisted of elevated line releases of fluorescent particles (FP) made from a light aircraft during crosswind traverses upwind of the tower. All of the releases were made at night and the effective release heights ranged from about 100 to 300 meters above the terrain. The tracer was sampled by means of a ground-level rotorod network consisting of five downwind lines and one crosswind line. In addition to these surface dosage data, vertical dosage measurements were made at various elevations on the TV tower. Supporting meteorological data consisted of wind and temperature measurements from instruments mounted on the tower. The sensors included light bivanes used to measure the fluctuations in the lateral and vertical components of the wind velocity. The wind and temperature profile instrumentation on the tower is described by Mitcham and Jehn (1964).

The general terrain in the vicinity of the site varies in elevation from 152 to 250 meters above mean sea level and may be classified as rolling terrain. In interpreting the measurements, it should be noted that the tower base is located in a slight depression near the top of a hill or ridge. The main portion of the ground-level dosage network is located to the north of the tower in a slight valley; the elevation of the valley floor was about 60 meters below the top of the ridge. The land in the vicinity of the tower is partially forested in contrast to the more open area in which the test array was located. Measurements of atmospheric structure made at the tower may therefore not be representative of the conditions at greater distances over the sampling array.

4.1 CLASSIFICATION OF TRIALS

For the present study, the Dallas Tower trials were classified into four categories: I, releases in a near-neutral layer with no inversion ($\partial T/\partial z < 0$); II, releases in a stable layer beneath an inversion cap ($\partial T/\partial z > 0$); III, releases in a stable layer above an inversion cap; and IV, releases made in light winds, when the wind speed at the 9-meter level on the Dallas Tower was less than 3 meters per second. Data for thirty-three trials categorized in this manner are presented in Table 4-1. Of

TABLE 4-1

SUMMARY OF DALLAS TOWER TRIALS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Stability Category	Trial Number	h(m)	$\bar{u}$ at h ($m\ sec^{-1}$)	u at 9m ($m\ sec^{-1}$)	σ_E at h (deg)	$\Delta T(C)$ ($T_h - T_{9m}$)	H (m)	$x_{max}obs$ (km)	$x_{max}obs/x_{max}pred$ (3)	(2)	(4)	$D_{max}obs/D_{max}pred$ (1)	(2)	$\frac{D_{cw}obs}{D_{cw}pred}$	D_Tobs/D_Tpred GCA	MRI
I	04	207	17.6	7.2	1.78	-0.61		29	0.96	2.00	1.64	1.09	1.69		0.92	1.46
(Release in near-	05	207	16.3	6.5	1.88	-1.22		18	0.58	1.00	1.04	0.88	1.41		0.66	1.04
neutral layer	06	116	13.4	6.7	3.45	-0.39		14	0.48	3.00	3.20	0.71	0.99		0.88	1.58
$\frac{\partial T}{\partial z} < 0$	07	207	17.6	7.2	2.40	-1.22		15	0.49	1.12	1.17	1.02	1.60		0.78	1.19
	08	300	20.0	6.3	1.19	-1.61									0.59	1.71
	18	137	12.5	5.2	2.11	-0.67		14	0.45	2.25	1.46	0.98	1.76		1.13	2.57
with no inversion)	20	228	13.5	5.0	0.82	-0.84		35	1.16	1.00	0.76	2.03	3.41	0.49	0.87	1.68
	21	228	13.0	3.7	1.01	-0.78		25	0.83	0.52	0.68	0.49	1.12	0.55	0.31	0.95
	22	320	14.2	6.1	0.79	-2.45		45	1.48	0.40	0.63	1.28	2.90	0.76	1.98	2.04
	23	320	14.3	3.9	1.12	-1.72		45	1.47	0.79	0.93	0.37	1.07	0.43	0.35	1.21
	25	137	9.8	3.4	1.49	0.00		21	0.69	1.86	1.53	1.25	0.95	0.74	0.38	0.98
	28	228	11.4	4.0	0.85	-1.39		44	1.43	1.00	0.97	0.76	1.48	0.37	0.72	1.52
	29	228	12.8	4.0	0.77	-1.05		50	1.63	1.20	0.99	0.23	0.49	0.38	0.17	0.36
	30	137	11.3	3.7	1.95	-0.49		42	1.36	4.20	4.08	0.59	1.07	1.13	0.43	1.04
	31*(6)	320	9.7	3.2	0.26	-1.95									~0	
	35	137	9.2	3.8	0.66	-0.39		28	0.94	2.00	0.84	1.94	1.90		1.01	2.12
II	02(5)	116	8.5	2.5	1.36	+3.22	183									
(Release in stable	03(5)	116	10.0	2.4	1.39	+3.72	228									
layer	11	116	14.5	5.4	1.08	+1.67	228	12	0.50	1.22	0.71	1.63	0.94		0.41	0.77
$\frac{\partial T}{\partial z} > 0$	17	183	11.0	4.3	1.19	+0.10	200	13	0.58	0.53	0.55	1.00	2.00		0.61	1.55
	26	137	12.8	3.1	1.01	+1.56	228	17	0.75	0.32	0.82	0.50	0.95	0.31	0.92	1.14
	27	137	10.1	2.6	0.86	+0.61	365	14	0.62	0.67	0.56	0.56	0.84	0.34	0.10	0.22
beneath inversion	33	137	11.4	3.1	0.39	+0.89	183								~0	
cap)	36	137	5.5	2.2	0.34	+0.50	228	47	2.06	1.53	0.67	0.28	0.63		0.17	0.16
	37	137	8.6	3.3	0.67			34	1.49		1.02	0.69			0.40	0.92
III	09(7)	207	11.0	3.0	0.38	+1.22	92	34		0.14	0.34	0.13	0.45		0.14	
(Release above	10(6)	207	14.6	4.8	0.37	+2.22	183					0.00			~0	
inversion cap)	16(6)	228	9.3	2.6	0.45	+0.39	92	35			0.39	0.01			~0	
	32(6)	228	10.5	2.6	0.24	+0.11	183	22			0.12	0.01			~0	
IV	01(6)	116	6.3	1.9	0.98	+2.50	92	33			1.85	0.01(5,6)			~0	
(Light wind)	12(5)	330	3.6	0.4	0.37	+1.33	137					0.00			~0	
	19**(5,7)	137	6.1	1.3	1.92	-0.49		3			0.31	0.44			0.09	
	34(5)	137	7.4	1.4	0.22	+0.78	320	40			0.36	0.22			0.08	

(1) $\frac{D\bar{u}}{Q} \cdot \frac{0.485}{h}$

(2) From Tables XI, XII, p. 34, Vol. I, MRI 161-FR33.

(3) $x_{max}pred : \overline{x_{max}obs}$

(4) $x_{max}pred \cdot \left[\frac{h}{\sigma_E(h)}\right]^{1/0.9}$

(5) Dosage maximum likely not on downwind sampling line.

(6) Cloud did not reach ground in 30 miles.

(7) Anomalous dosage pattern.

* Light turbulence at release height - cloud not expected to reach ground.

** Thunderstorms in area.

these, sixteen releases were made in near-neutral stratification, nine in a stable layer beneath an inversion cap, four above an inversion cap and four in light wind situations. Borderline cases were evaluated carefully and placed in what appeared to be the most appropriate category. Columns 1 through 8 of Table 4-1 summarize the basic meteorological parameters for each of the trials. The symbol H represents the height of the capping inversion base and h is the effective release height.

4.2 COMPARISON OF OBSERVED AND PREDICTED DOSAGE PROFILE CHARACTERISTICS

In this section, significant features of the observed ground-level dosage patterns are compared with predicted values. These features include the distance x_{max} at which the maximum dosage occurs, the maximum dosage D_{max}, dosages observed within the 50 percent limits of D_{max} given by the predicted ground-level dosage profile, the mean dosage along the crosswind row of samplers, and the total area dosage calculated from normalized ground-level dosage profiles. Predicted values include those previously determined by MacCready, et al (1961) and new values calculated from the GCA model. In the case of x_{max}, the mean of the observed values of the data set is also considered a predicted value. No values were computed by MRI (MacCready, et al, 1961) for Trials 10, 16, and 32 in which the releases were made above an inversion cap, or in the presence of light winds. These trials are therefore not included in the comparisons of observed and predicted dosage parameters discussed below and summarized in Tables 4-1 to 4-5.

4.2.1 Distance to Maximum Dosage. Column 9 of Table 4-1 presents the distance x_{max}obs at which the highest measured value of the dosage occurred. The distribution of the ratio x_{max}/h, calculated from Columns 3 and 9, for all the trials in Categories I and II has a mean value of 156 and a standard deviation of 75. No differences in the ratio distributions for the two categories are discernible, although the small sample size in Category II makes any comparison rather qualitative.

Columns 10, 11, and 12 of Table 4-1 compare the observed distance at which the maximum dosage occurred to the predicted distance through use of the ratio x_{max}obs/x_{max}pred. Ratios entered in the table are based on predicted values calculated by three procedures as indicated by numbers in the column heading. The predicted value of x_{max} used to obtain the ratios in Column 10, headed (3), is the mean of the observed x_{max} values for all trials included in the particular stability class being considered. The predicted distances used to obtain the ratios in Column 11, headed (2), were calculated by MRI from the expression

$$x_{max} = \frac{h}{3i_e^2} \quad , \tag{4-1}$$

in which h is the release height and i_e^2 is a measure of the effective

TABLE 4-2

SUMMARY OF OBSERVED AND PREDICTED GROUND-LEVEL DOSAGE PROFILES FOR DALLAS TOWER TRIALS, CATEGORIES I AND II

	$\frac{x_{max}obs}{x_{max}pred}$			$\frac{D_{max}obs}{D_{max}pred}$		$\frac{D_{T}obs}{D_{T}pred}$	
CATEGORY I	GCA	MRI	DATA MEAN*	GCA	MRI	GCA	MRI
N	14	14	14	14	14	15	15
Mean	1.42	1.60	1.00	0.97	1.56	0.74	1.43
Median	1.02	1.16	0.95	0.93	1.44	0.72	1.46
Standard Deviation	1.01	1.05	0.43	0.53	0.78	0.45	0.99
CATEGORY II							
N	5	5	5	5	5	6	6
Mean	0.66	0.85	1.00	0.79	1.07	0.44	1.13
Median	0.69	0.67	0.68	0.62	0.94	0.40	0.84
Standard Deviation	0.11	0.50	0.73	0.55	0.54	0.27	0.72

* $x_{max}pred = \overline{x_{max}obs}$

TABLE 4-3

CUMULATIVE FREQUENCY DISTRIBUTION OF $D_{max}obs/D_{max}pred$ FOR DALLAS TOWER TRIALS, CATEGORIES I AND II. SET A ASSUMES MULTIPLE REFLECTION; SET B ASSUMES NO REFLECTION.

I		II			
		A		B	
$\frac{D_{max}obs}{D_{max}pred}$	Cumulative Frequency (%)	$\frac{D_{max}obs}{D_{max}pred}$	Cumulative Frequency (%)	$\frac{D_{max}obs}{D_{max}pred}$	Cumulative Frequency (%)
0	0	0	0	0	0
0.05	0	0.05	0	0.05	0
0.10	0	0.10	0	0.10	0
0.15	0	0.15	28.6	0.15	12.5
0.20	0	0.20	28.6	0.20	25.0
0.25	6.7	0.25	42.8	0.25	25.0
0.30	6.7	0.30	42.8	0.30	37.5
0.35	6.7	0.35	42.8	0.35	37.5
0.40	13.3	0.40	42.8	0.40	37.5
0.45	13.3	0.45	57.1	0.45	37.5
0.50	20.0	0.50	71.4	0.50	37.5
0.55	20.0	0.55	71.4	0.55	50.0
0.60	26.7	0.60	85.7	0.60	62.5
0.65	33.3	0.65	85.7	0.65	62.5
0.70	33.3	0.70	85.7	0.70	62.5
0.75	33.3	0.75	85.7	0.75	75.0
0.80	46.7	0.80	85.7	0.80	75.0
0.85	53.3	0.85	85.7	0.85	75.0
0.90	53.3	0.90	85.7	0.90	75.0
0.95	60.0	0.95	85.7	0.95	87.5
1.00	73.3	1.00	85.7	1.00	87.5
1.05	73.3	1.05	85.7	1.05	87.5
1.10	73.3	1.10	85.7	1.10	87.5
1.15	73.3	1.15	85.7	1.15	87.5
1.20	73.3	1.20	85.7	1.20	87.5
1.25	73.3	1.25	85.7	1.25	87.5
1.30	80.0	1.30	85.7	1.30	87.5
1.35	86.7	1.35	85.7	1.35	87.5
1.40	86.7	1.40	100.00	1.40	87.5
1.45	86.7			1.45	87.5

TABLE 4-3 (continued)

I		II			
		A		B	
$\frac{D_{max}obs}{D_{max}pred}$	Cumulative Frequency (%)	$\frac{D_{max}obs}{D_{max}pred}$	Cumulative Frequency (%)	$\frac{D_{max}obs}{D_{max}pred}$	Cumulative Frequency (%)
1.50	86.7			1.50	100.00
1.55	86.7				
1.60	86.7				
1.65	86.7				
1.70	86.7				
1.75	86.7				
1.80	86.7				
1.85	86.7				
1.90	86.7				
1.95	86.7				
2.00	93.3				
2.05	93.3				
2.10	100.00				

TABLE 4-4

SUMMARY STATISTICS FOR RATIO DISTRIBUTIONS
OF OBSERVED AND PREDICTED DOSAGES

	N	Median	Mean	σ	Confidence Limits	
CATEGORY						
		(a) To Accompany Table 4-3				
I	15	0.83	0.95	0.54	0.24	2.07
II A	7	0.43	0.48	0.44	0.11	1.38
II B	8	0.55	0.60	0.44	0.12	1.48
		(b) To Accompany Table 4-5				
I	275	0.54	0.63	0.45	0.08	1.55
II A	157	0.11	0.19	0.27	0.05	0.70
II B	179	0.15	0.28	0.34	0.00	0.80

TABLE 4-5

CUMULATIVE FREQUENCY DISTRIBUTION OF D_{obs}/D_{pred} FOR DALLAS TOWER TRIALS, CATEGORIES I AND II. SET A ASSUMES MULTIPLE REFLECTION; SET B ASSUMES NO REFLECTION.

I		II			
		A		B	
$\frac{D_{obs}}{D_{pred}}$	Cumulative Frequency (%)	$\frac{D_{obs}}{D_{pred}}$	Cumulative Frequency (%)	$\frac{D_{obs}}{D_{pred}}$	Cumulative Frequency (%)
0	0.4	0	18.5	0	14.0
0.05	2.5	0.05	38.8	0.05	34.1
0.10	7.3	0.10	47.7	0.10	40.2
0.15	12.7	0.15	56.0	0.15	50.3
0.20	22.5	0.20	71.3	0.20	55.3
0.25	26.5	0.25	74.5	0.25	60.9
0.30	28.4	0.30	85.3	0.30	64.2
0.35	33.1	0.35	89.2	0.35	67.6
0.40	38.5	0.40	91.0	0.40	70.3
0.45	42.5	0.45	92.4	0.45	74.9
0.50	47.3	0.50	93.0	0.50	80.4
0.55	51.6	0.55	93.6	0.55	86.0
0.60	55.6	0.60	94.2	0.60	88.8
0.65	59.2	0.65	94.9	0.65	92.2
0.70	61.8	0.70	95.5	0.70	92.7
0.75	66.2	0.75	95.5	0.75	94.4
0.80	71.3	0.80	95.5	0.80	94.9
0.85	75.3	0.85	95.5	0.85	94.9
0.90	76.0	0.90	96.1	0.90	95.5
0.95	80.7	0.95	96.1	0.95	95.5
1.00	83.3	1.00	96.8	1.00	95.5
1.05	84.4	1.05	96.8	1.05	95.5
1.10	86.2	1.10	96.8	1.10	95.5
1.15	87.6	1.15	96.8	1.15	95.5
1.20	89.1	1.20	97.4	1.20	96.6
1.25	89.4	1.25	97.4	1.25	96.6
1.30	90.2	1.30	98.0	1.30	97.2
1.35	91.6	1.35	98.0	1.35	97.2
1.40	92.7	1.40	98.0	1.40	97.2
1.45	94.1	1.45	98.0	1.45	97.2

TABLE 4-5 (continued)

I		II			
		A		B	
$\frac{D_{obs}}{D_{pred}}$	Cumulative Frequency (%)	$\frac{D_{obs}}{D_{pred}}$	Cumulative Frequency (%)	$\frac{D_{obs}}{D_{pred}}$	Cumulative Frequency (%)
1.50	94.2	1.50	99.36	1.50	98.3
1.55	94.9	1.55	99.36	1.55	98.3
1.60	96.0	1.60	99.36	1.60	98.3
1.65	96.7	1.65	99.36	1.65	99.44
1.70	97.1	1.70	100.00	1.70	99.44
1.75	97.1			1.75	99.44
1.80	97.8			1.80	99.44
1.85	97.8			1.85	99.44
1.90	97.8			1.90	99.44
1.95	97.8			1.95	100.00
2.00	98.5				
2.05	98.5				
2.10	99.27				
2.15	99.27				
2.20	99.64				
2.25	100.00				

vertical turbulence intensity. The ratios in Column 12, headed (4), were calculated from the GCA model formula (see Section 2.5) which becomes

$$x_{max}pred = \left[\frac{h}{\sigma'_E(h)} \right]^{1/0.9} \tag{4-2}$$

when β is taken to be 0.9 and x_1 is taken to be 1.0 meter.

The distributions of the ratios presented in these three colums have been analyzed for their means, medians and standard deviations. The results grouped by stability category, are shown in Table 4-2. For the fourteen trials in which the release was made in a near-neutral layer with no inversion, both the MRI and GCA models tend to underestimate the distance to the maximum dosage. The mean value of x_{max} is 1.60 for the MRI model and 1.42 for the GCA model. Corresponding median values are 1.02 and 1.16 respectively. The standard deviations of the distributions of the ratios computed by these two techniques are nearly equal, and both are approximately 2.5 times larger than the standard deviation of the data-mean distribution. If Trials 6 and 30 are eliminated from consideration, the mean value of the ratio is 1.26 for the MRI model and 1.05 for the GCA model; the corresponding values of the standard deviations are reduced to 0.61 and 0.33 respectively. The GCA model standard deviation in this case is somewhat smaller than that for the data-mean distribution, which has a standard deviation of 0.40.

For the five trials in which the releases were in a stable layer beneath an inversion cap, both models tend to overestimate the distance to the maximum dosage. The mean and standard deviations for the GCA model are respectively 0.66 and 0.11, while the corresponding values for the MRI model are 0.85 and 0.50. Median values for all three distributions are nearly identical and are approximately equal to 0.7. The use of either model results in a smaller standard deviation than that obtained by the use of the data mean. A sixth trial can be added when comparing ratios based on the GCA model with those based on the data mean. When this is done, the standard deviations based on the GCA model and the data mean are, respectively, 0.18 and 0.64.

The distance at which the dosage level first becomes equal to one-half the maximum dosage occurs on the steeply rising portion of the dosage-distance curve and is frequently better defined than the distance at which the maximum occurs. A comparison of the observed distance at which this dosage level first occurs to the distance predicted by the GCA model was made using the ratio $x_{max/2}obs/x_{max/2}pred$. In general, the agreement between observed and predicted values is slightly poorer than in the case of x_{max}. For example, the mean values of the ratio and the standard deviation of the distribution are 1.38 and 1.31, respectively, for the fourteen releases of Category I; these values are reduced to 1.04

and 0.43 respectively when Trials 6 and 30 are omitted. For the six releases of Category II, the mean value of the ratio is 1.00 and the standard deviation 0.28 when the model calculations do not include the multiple reflection terms. For five of these releases, the ratios were also computed assuming H equal to the height of the inversion with the result that the mean value of the ratio was 0.89 and the standard deviation 0.28. These results suggest that the use of the distance to one-half the maximum, $x_{max/2}$, offers no advantage over x_{max} in describing the observed dosage profiles.

4.2.2 Maximum Ground-Level Dosage. The observed maximum ground-level dosages are compared to the values predicted by the Gaussian model

$$\frac{D_{max}}{Q} = \frac{0.485}{\bar{u}h}$$

by means of the ratio $D_{max}obs/D_{max}pred$. In principle, the mean wind speed for the dosage model should be measured at the height of the sampler. The measurement height closest to the height of the samplers of the ground-level network in these trials was 9 meters, and Column 13 of Table 4-1 presents ratios using the 9-meter wind speed (GCA model). Column 14 presents equivalent ratios determined by MRI in which $\bar{u}$ is an average wind speed for the layer between the ground and the release height. The results for Categories I and II are summarized by the mean values and standard deviations of the distributions listed in Table 4-2, in which N is the number of trials. When the effective release height was in a stable layer above an inversion cap (Category III), the tracer material reached ground level only in small amounts at widely scattered points. During the light wind cases (Category IV) the vertical expansion of the plume either was insufficient to bring the cloud to the ground within the sampling network, or the ground-level dosage patterns were anomalous due to the presence of large fluctuations in wind direction. For the fourteen trials of Category I, the mean value of the ratio $D_{max}obs/D_{max}pred$ is 0.97 when the predicted value is computed from the GCA model and 1.56 when computed from the MRI model. The corresponding standard deviations based on the two models are 0.53 and 0.78 respectively. For the five trials of Category II, the mean value of the ratio based on the GCA model is 0.79 and the mean value based on the MRI model is 1.07. There is no significant difference between the standard deviations based on the two models. Differences in the mean values of the GCA and MRI ratio distributions are principally due to the differences in the mean wind speed used in the calculations.

Ordered values of the ratio of observed and predicted values of the maximum ground-level dosages and cumulative frequency distributions of these ratios are presented in Table 4-3 for the trials in Categories I and II. Predicted values of D_{max} were determined from ground-level dosage profiles calculated by means of Equation (2-10) using the σ_E values

at release height and the mean wind speeds at a height of 9 meters given in Table 4-1. The model standard deviation of the vertical dosage distribution σ_z was calculated from Equation (2-14)

$$\sigma_z(x) = \sigma_E' \, x_1 \left[\frac{x}{x_1} \right]^{\beta} ,$$

where x_1 is assumed to be 1 meter and σ_E' is in radians. Two sets of ratios are reported for Category II. In the first set (A), the values of H shown in Table 4-1 have been used to calculate the predicted maximum dosage, and the results thus include the effects of multiple reflection. In the second set of ratios (B), the predicted values of D_{max} do not include multiple-reflection effects. Maximum dosage values computed by the two procedures differ significantly only when the effective release height h is just beneath the base of the capping inversion. Properties of the above ratio distributions are summarized in Part (a) of Table 4-4, which lists the sample size N, arithmetic mean, median, standard deviation, and the 5- and 95-percent confidence limits. The arithmetic mean of the distribution for Category I (near-neutral) is approximately unity; for sets A and B of Category II, the arithmetic mean of the distributions is approximately 0.5. The corresponding coefficients of variability (σ/mean) range from 0.57 for Category I to 0.92 and 0.73 for sets A and B respectively. There is approximately one order of magnitude difference between the 0.05 and 0.95 confidence limits of the ratio distribution for each of the three classes. Summary statistics of Part (a) of Table 4-4 are based on a greater number of trials than the number that could be used in preparing Table 4-2.

4.2.3 Dosages within 50 Percent Limits of D_{max}pred. Observed and predicted dosage values within the 50-percent limits of D_{max} given by the GCA model have been compared by means of the ratio D_{obs}/D_{pred}. Predicted values for Categories I and II were determined from the dosage profiles obtained from Equation (2-10) by the procedures outlines in the preceding paragraph. Ordered values of the ratio of observed and predicted dosages and cumulative frequency distributions of these ratios for these stability categories are presented in Table 4-15. Summary statistics for these distributions are presented in Part (b) of Table 4-4. The results support the conclusions reached previously from a study of the observed and predicted maximum values of ground-level dosage shown in Table 4-2. The mean and median of the ratio distribution for Category I are two to five times larger than the corresponding values for sets A and B of Category II. Also, the coefficients of variability for sets A and B (1.42 and 1.21) are nearly twice as large as that for Category I (0.71).

4.2.4 Ground Level Dosage Profiles. Figures 4-1 through 4-9 show the normalized dosage D/D_{max} as a function of downwind distance x for

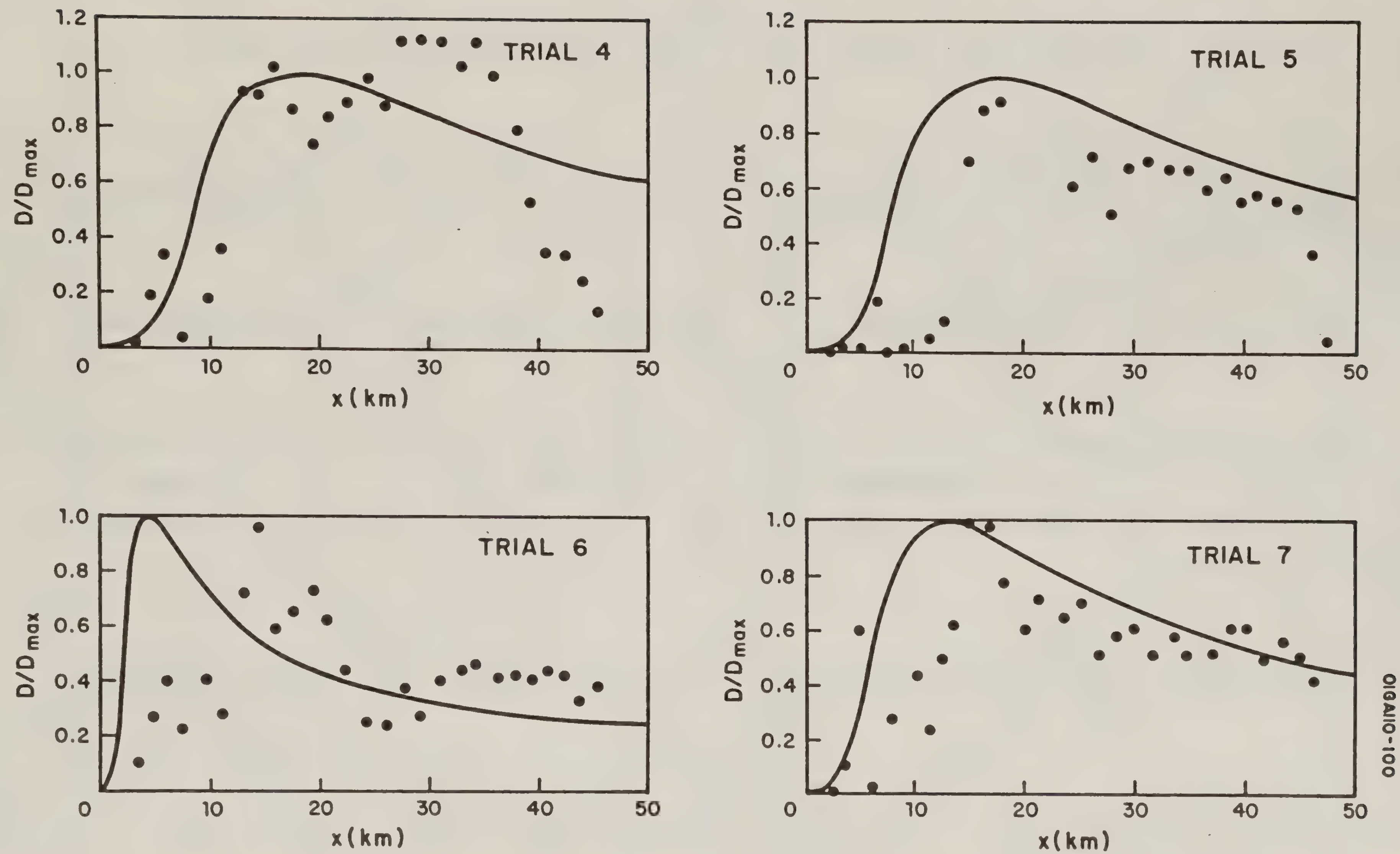

Figure 4-1. Ground-level dosage profiles for near-neutral cases (Trials 4, 5, 6, and 7) at Dallas Tower.

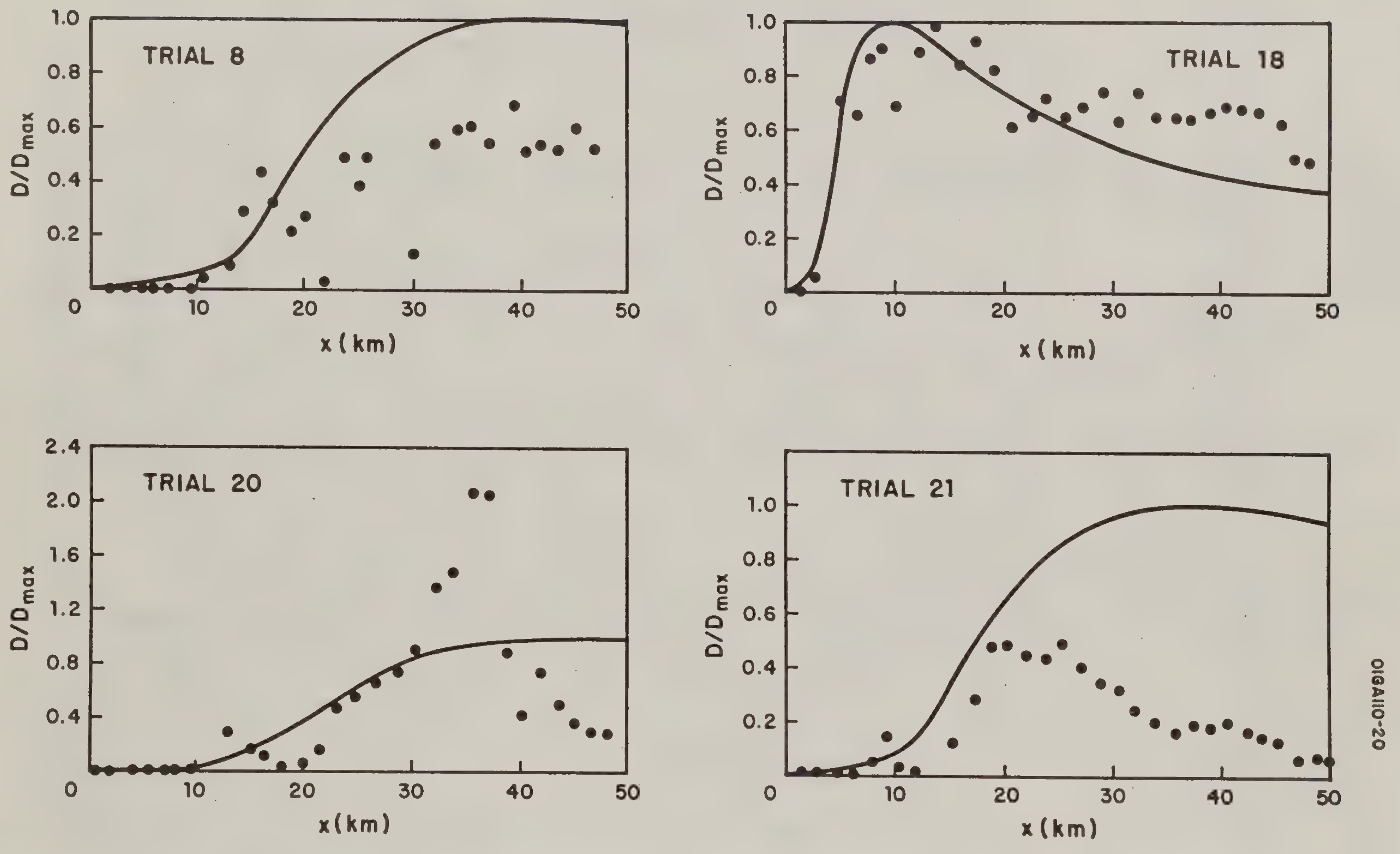

Figure 4-2. Ground-level dosage profiles for near-neutral cases (Trials 8, 18, 20, and 21) at Dallas Tower.

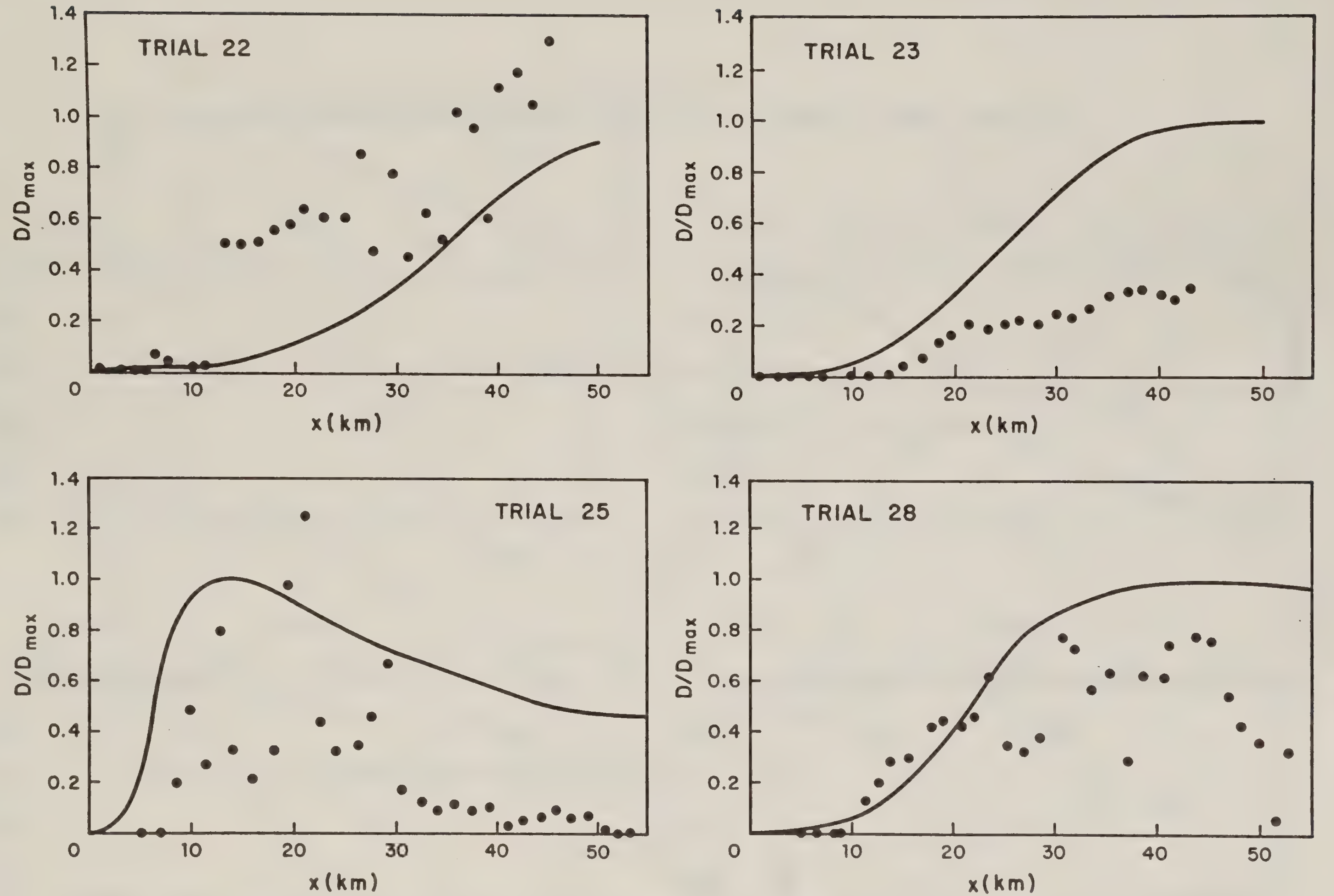

Figure 4-3. Ground-level dosage profiles for near-neutral cases (Trials 22, 23, 25, and 28) at Dallas Tower.

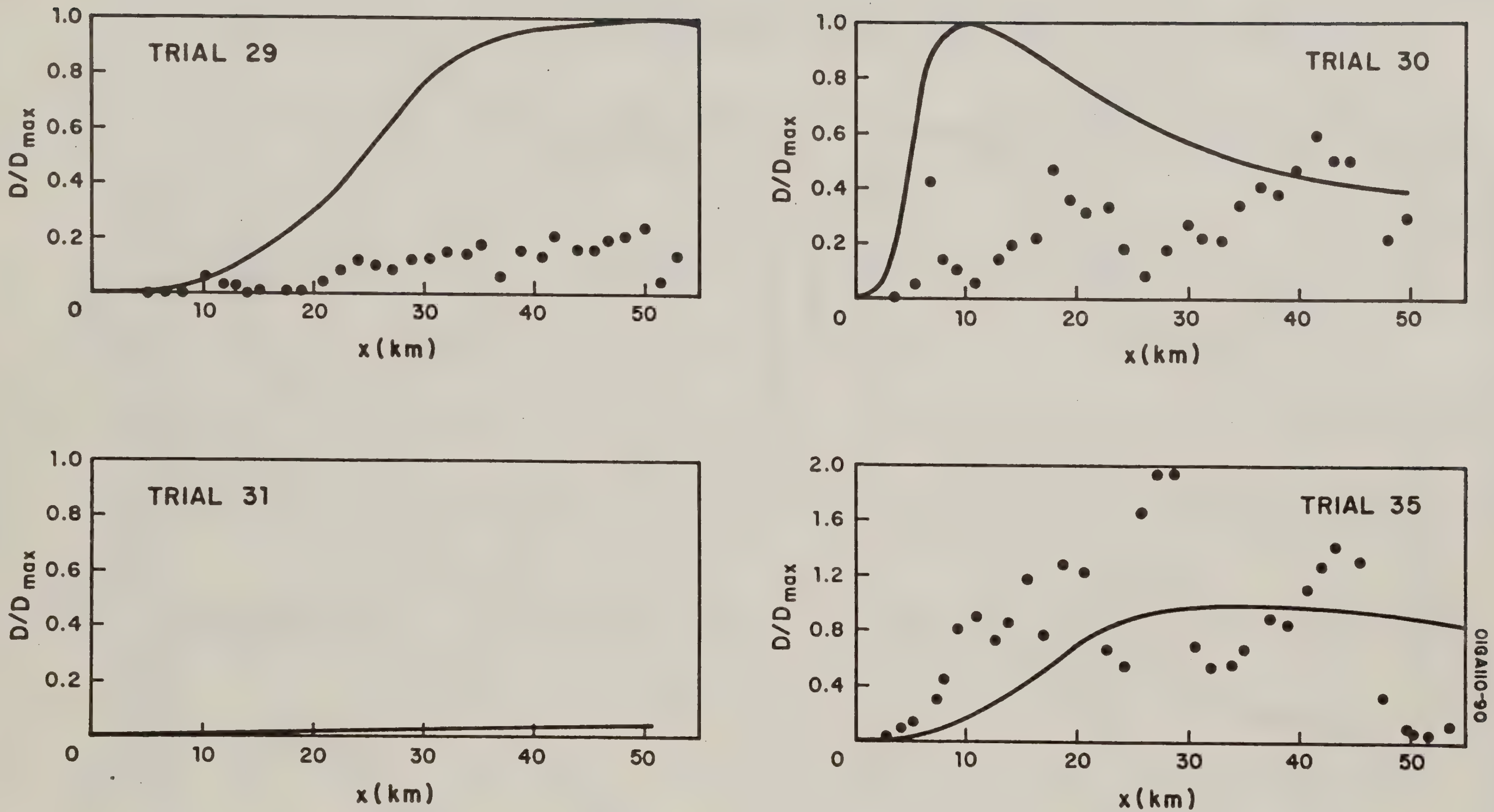

Figure 4-4. Ground-level dosage profiles for near-neutral cases (Trials 29, 30, 31, and 35) at Dallas Tower.

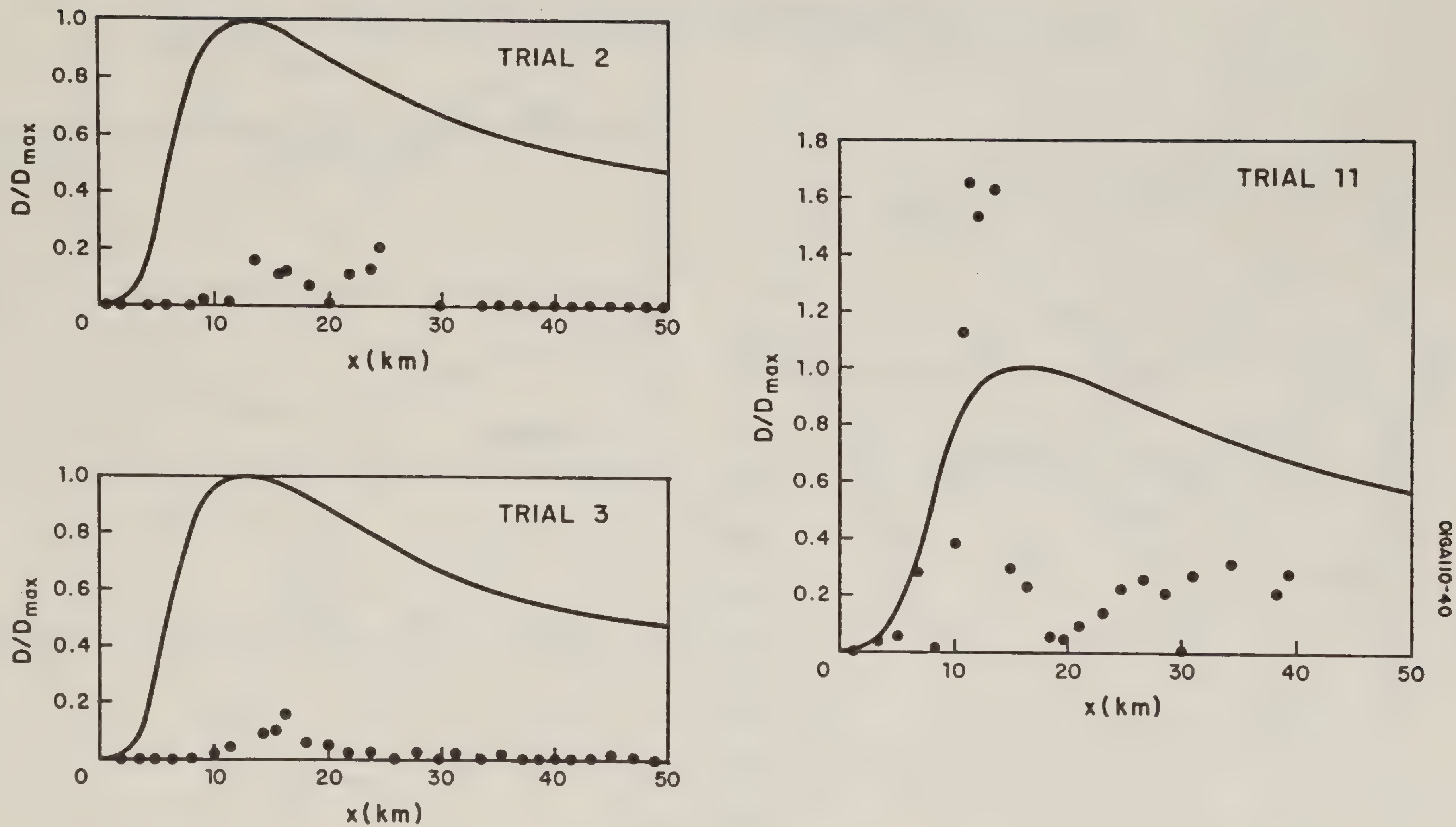

Figure 4-5. Ground-level dosage profiles for releases beneath inversion cap (Trials 2, 3, and 11) at Dallas Tower.

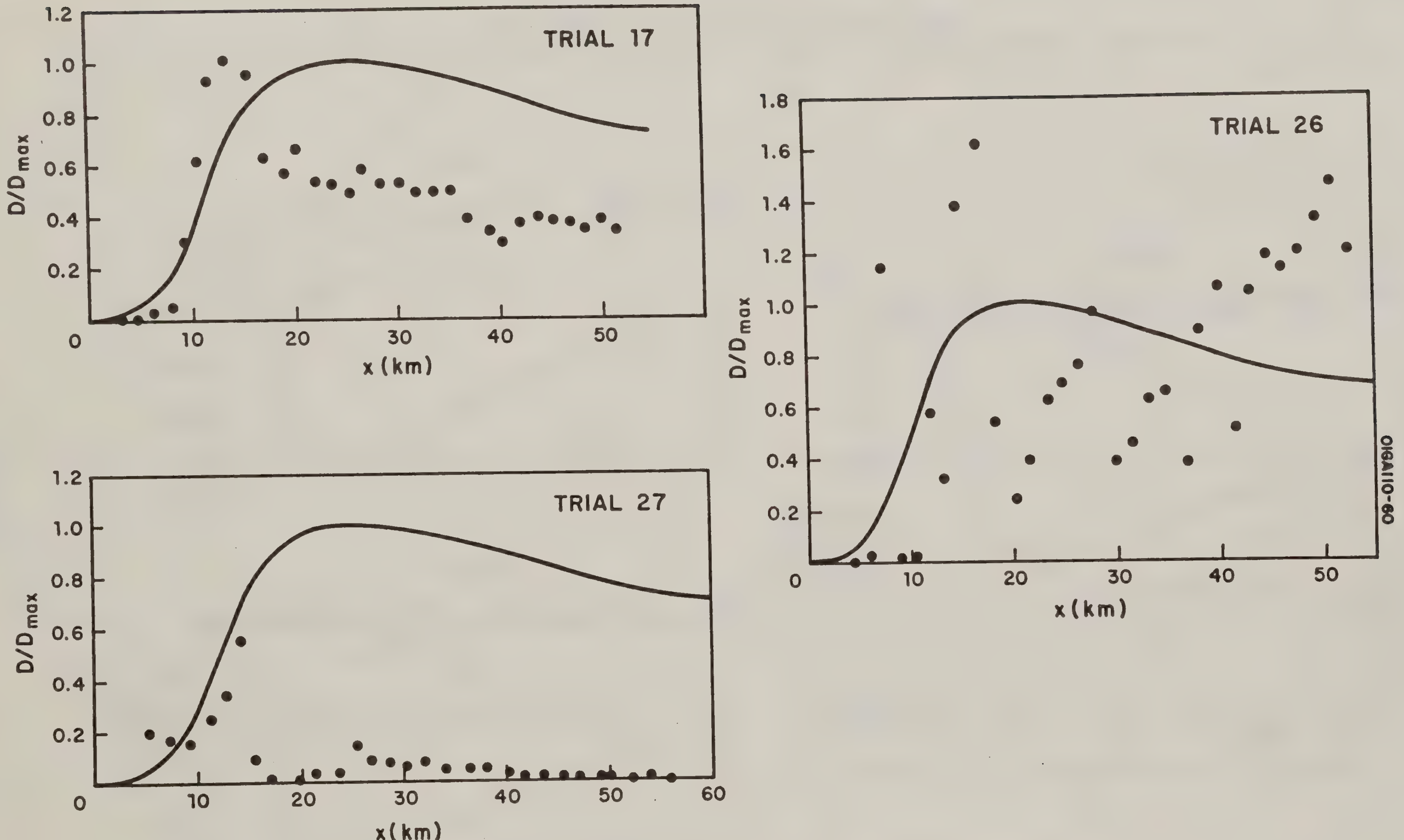

Figure 4-6. Ground-level dosage profiles for releases beneath inversion cap (Trials 17, 26, and 27) at Dallas Tower.

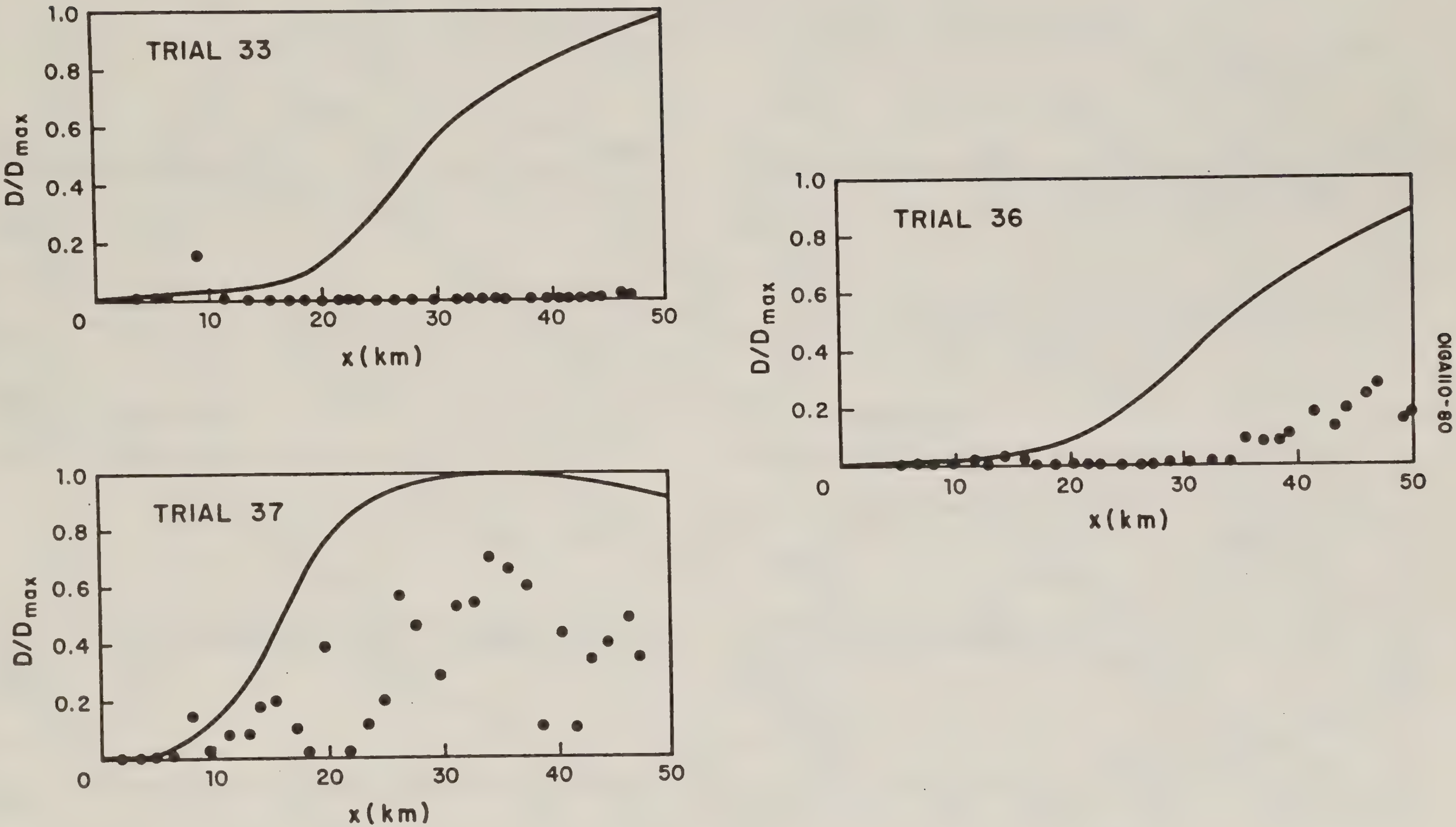

Figure 4-7. Ground-level dosage profiles for stable cases with releases beneath inversion cap (Trials 33, 36, and 37) at Dallas Tower.

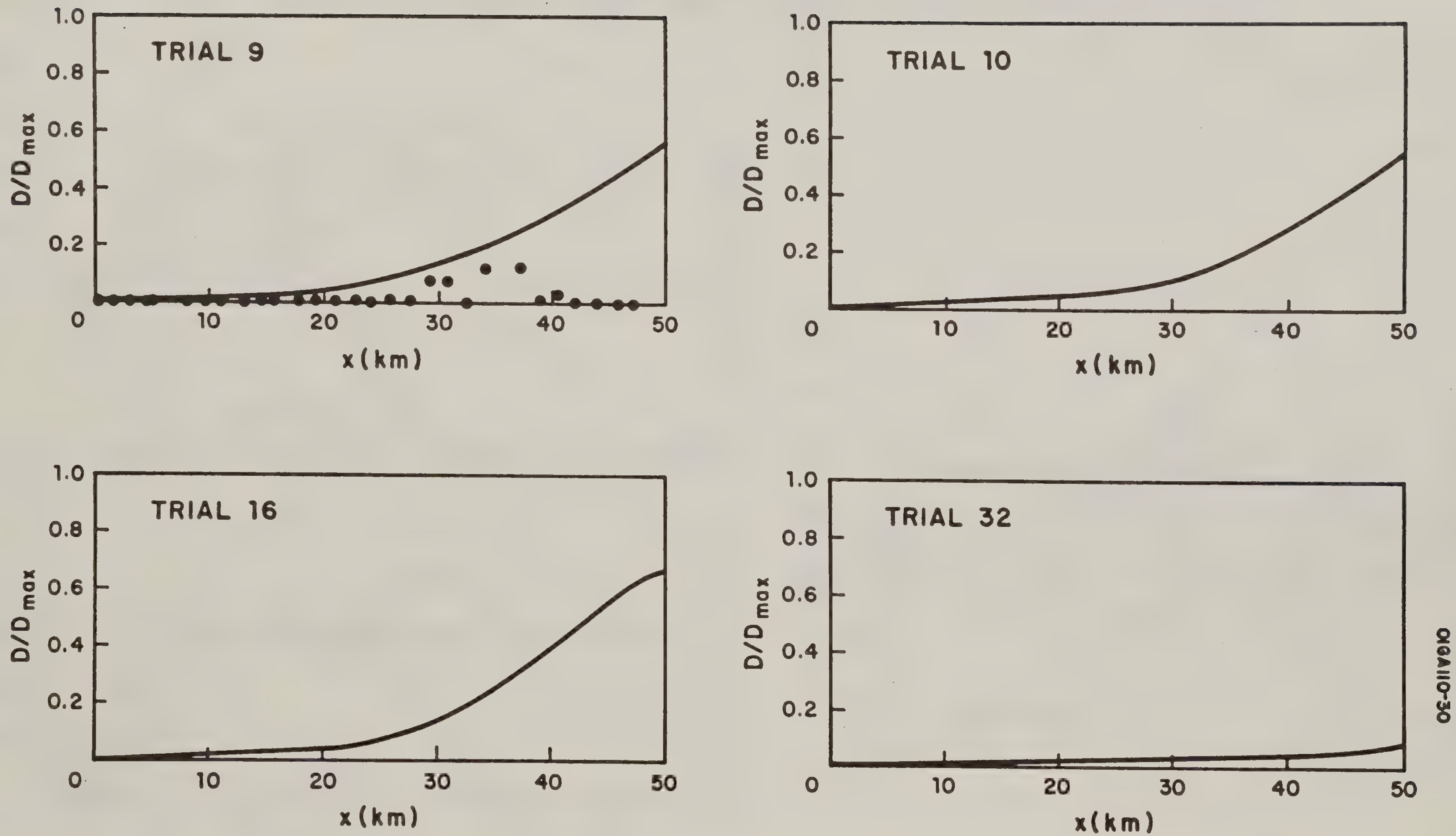

Figure 4-8. Ground-level dosage profiles for releases above inversion cap (Trials 9, 10, 16, and 32) at Dallas Tower.

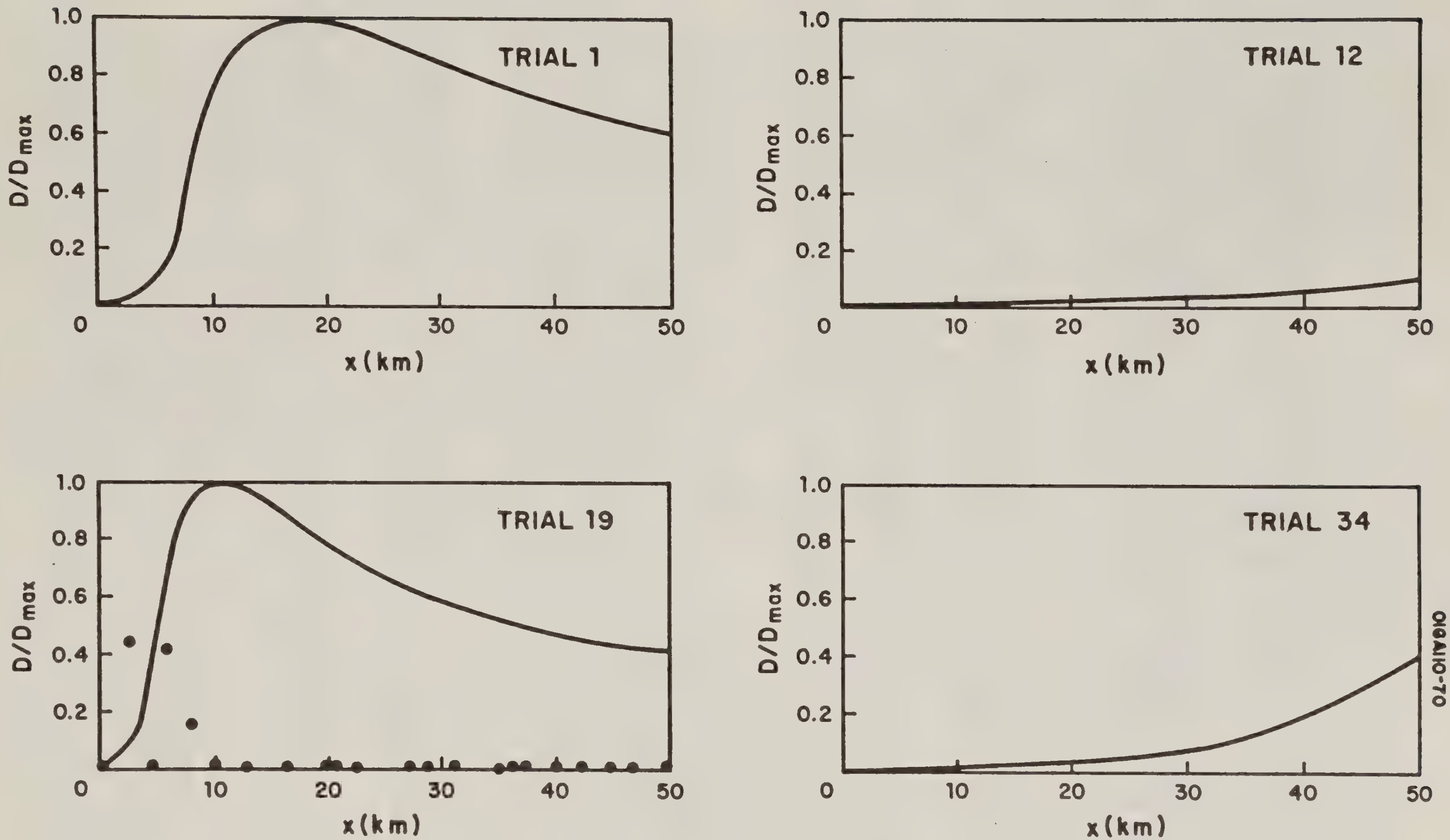

Figure 4-9. Ground-level dosage profiles for light-wind cases (Trials 1, 12, 19, and 34) at Dallas Tower.

each of the trials in the Dallas Tower series. The normalized dosages are computed as the ratio of the observed dosage to the predicted maximum dosage. The solid curve in each figure is the predicted normalized dosage distribution based on the GCA model (Equation 2-10). Figures 4-1 through 4-4 are for cases under near-neutral thermal stratification. Figures 4-5, 4-6, and 4-7 are for cases where the tracer was released in a stable layer beneath the inversion cap. The cases in Figure 4-8 refer to releases above the inversion cap. The cases for a light-wind category are presented in Figure 4-9.

From these figures, it is apparent that in Trials 4, 5, 6, 7, 18, 20, 28, and 35, the observed normalized dosage distributions agree reasonably well with those predicted. All of these cases fall in the near-neutral category, and the mean wind speeds both at the release height and at 9 meters are higher, on the average, than for the rest of the trials. With the exception of Trial 35 the wind speeds at release height exceed 11.4 meters per second and those at 9 meters are all greater than 4 meters per second. Under the same category, cases with low wind speeds at 9 meters such as Trials 21, 23, 29, and 30, show considerably less agreement between observed and predicted dosages, especially for distances greater than 15 to 20 kilometers.

For releases beneath the base of an inversion cap, the agreement between observed and predicted dosages is generally poor. One feature common to Trials 11, 17, 26, and 27 (Figures 4-5 and 4-6) is that the peak dosages occur at relatively short distances from the source. In these cases, the 9-meter wind speeds range from 2.6 to 5.4 meters per second, while the rest of the cases all have wind speeds below 3.1 meters per second. For Trials 9, 10, 16, and 32 (Figure 4-8), where the releases were above the inversion, essentially no dosage was observed at the ground. It should be remembered that the model generally predicts very low dosages in most cases (see Trial 32). This is true also for Trials 12 and 34 in the light-wind category. In this latter category a large discrepancy exists between the observed and the predicted dosages for Trials 1 and 19 in Figure 4-9.

The areas beneath the curves of Figures 4-1 through 4-9 are relative measures of the total dosage D_T along the sampling line. A quantitative measure of the degree of conformity between the observed and predicted dosages is the ratio $D_T obs/D_T pred$. Values of this ratio computed from the curves of Figures 4-1 through 4-9 are presented in Column 17 of Table 4-1. Computed ratios from the MRI model (Figures 11, 12, and 13 of MacCready, et al, 1961) are shown in Column 18 for comparison.

In Column 17 it is evident that the highest values of the ratio occur in the near-neutral category, in which the wind speed is generally high. Closer examination shows that the ratio tends to increase with increasing 9-meter wind speed. For example, Trials 4, 5, 6, and 7 all have $u_{9m} \geq 6.5$ meters per second and the ratios all exceed 0.66. On the

other hand, Trials 19, 27, and 34 with $\overline{u}_{9m} \leq 4$ meters per second all have ratios less than 0.10. In between these two regions are intermediate values of both the ratio and wind speed (Trials 11, 27, 23, and 30). The above relationship between $D_T$obs/$D_T$pred and wind speed also hold approximately if the wind speed at release height is substituted for the 9-meter wind speed.

The last column in Table 4-1 gives D_T ratios based on profiles predicted by the MRI model. Little variation in the ratios with wind speed is apparent. This and the fact that the majority of the values exceed unity is accounted for by the use of a layer wind speed in the MRI model application. For cases in the near-neutral category, the GCA model yields a mean ratio of 0.74 and a standard deviation of 0.45 while the MRI model gives a mean ratio of 1.43 and a standard deviation of 0.99. For cases in the stable, beneath-cap-release category the mean and the standard deviation from the GCA model are respectively 0.44 and 0.27; while those from the MRI model are respectively 1.13 and 0.72.

4.2.5 Dosage at Crosswind Sampling Line. As mentioned previously, dosage measurements during twelve of the Dallas Trials were taken along a crosswind line located about 40 kilometers downwind from the tower. Dosages were measured at 13 fixed stations spaced at intervals of about 3.2 kilometers along this crosswind line.

Column 15 of Table 4-1 presents values of the ratio of $\overline{D_{cw}\text{obs}}/D_{cw}$pred for 10 of the 12 trials. The overbar indicates the mean of the dosages measured along the crosswind line. Distances to the sampling line were measured along the wind direction observed at release height from the ground projection of the release line to the midpoint of the crosswind line. The observed values of $\overline{D}/Q$ are mean values of those stations judged to be within the central portion of the cloud. Points outside of this segment were discarded to eliminate edge effects. The predicted dosages were calculated by means of Equation (2-10).

It is seen that the ratios range from 0.31 to 1.13. The mean ratio for all 10 trials is 0.55; similarly, for the first 9 trials, discarding Trial 30, the mean ratio is 0.49. On the average, therefore, the GCA model overestimates the observed dosage by a factor of about two. Examination of these ratios with respect to the other parameters, such as the wind speed at 9 meters and σ_E at release height, shows no apparent relationships.

4.3 CROSSWIND VARIABILITY OF DOSAGE

The coefficient of crosswind variability of dosage is defined as the standard deviation of the dosages measured on the crosswind line divided by their mean. Table 4-6 presents values of this coefficient for trials in which crosswind measurements were available. For some of these trials, it was apparent that several of the samplers were outside the central

TABLE 4-6

CROSSWIND VARIABILITY OF DOSAGE FROM DALLAS TOWER TRIALS

Trial No.	$\sigma_D/\overline{D}$	No. of Observations	Comments
20	0.62	13	
21	0.46	7	East half of line missed
22	0.71	11	
23	0.25	11	
25	0.90	7	East half of line missed
26	0.54	11	
27	0.34	6	West half of line missed
28	0.37	13	
29	0.85	11	
30	0.27	11	
31	1.82	13	Very low measured dosages
32	1.02	13	Very low measured dosages
33	0.95	13	Very low measured dosages

portion of the tracer cloud. Inclusion of dosages from these stations would be expected to give an underestimation of the mean dosage and an overestimation of the standard deviation; both effects would tend to overestimate the coefficient of variability, and therefore these measurements were not included. The range of values of this statistic is similar to that found at a much shorter travel distance for the ground-level line releases of the BC-412 diffusion trials (Cramer, et al, 1965).

Because of the small sample size no attempt has been made to relate the calculated variability coefficients to stability parameters. Nevertheless, Trials 26 and 27, both stable cases, show values of σ_D/D lower than most of the near-neutral cases. This suggests a decrease in variability with increasing stability in rough conformity to the findings of the BC-412 trials. Trials 31, 32, and 33 give the highest values for the variability coefficient. These are cases where the mean wind at 9 meters is low and the observed dosages are small and erratic.

4.4 SUMMARY OF THE DALLAS TOWER ANALYSIS

The results of the preceding analysis show the elevated line-source technique to be subject to important meteorological restrictions. The principal conclusions may be conveniently summarized in terms of the four categories which were used to classify the trials.

Category I: Releases in a Near-Neutral Layer with No Inversion

Category II: Releases in a Stable Layer Beneath an Inversion Cap

Ground-level dosage profiles for these two categories are in fair agreement with profiles predicted by both the MRI and GCA models. The utility of the two models is shown by the summary statistics presented in Table 4-7. No significant difference between the success of the two models is evident. It may be noted however that the GCA model tends to predict dosages slightly in excess of the observed values, while the MRI model tends to predict dosages that are somewhat smaller than the observed values. This difference results primarily from the use of different wind speeds in the two models. Perhaps the most general of the dosage statistics are those for total ground-level dosage along the sampling line. The observed total dosages are about 65 percent of the values predicted by the GCA model and about 125 percent of the values predicted by the MRI model. It can be seen from Table 4-7 that both models predict the distance at which the maximum ground-level dosage occurs with comparable precision. The distance to the maximum dosage varies from about 100 to 300 times the release height.

Category III: Releases in a Stable Layer Above an Inversion Cap

In three of the four trials in which the release was made in the decoupled layer above an inversion cap, the material did not reach the ground level in 30 miles. In the fourth trial, dosages were small and the dosage pattern anomalous.

TABLE 4-7

SUMMARY STATISTICS OF DOSAGE PARAMETERS FOR COMBINED CATEGORIES I AND II

Parameter	Model	Median	Mean	Range
$D_{max}obs/D_{max}pred$	MRI	1.09	1.43	0.49 - 3.41
	GCA	0.82	0.90	0.23 - 2.30
D_Tobs/D_Tpred	MRI	1.19	1.25	0.16 - 2.57
	GCA	0.61	0.66	0.10 - 1.98
D_{obs}/D_{pred} within 50% limits of $D_{max}pred$	GCA	0.31	0.45	0.00 - 2.23
$\overline{D_{cw}obs}/D\ pred$	GCA	0.46	0.55	0.31 - 1.13
$x_{max}obs/x_{max}pred$	MRI	1.12	1.40	0.32 - 4.20
	GCA	0.95	1.21	0.55 - 4.08

Category IV: Light Wind Cases

In the four light wind cases, either the vertical intensity of turbulence was insufficient to bring the material to the ground within 30 miles or the dosage patterns were anomalous.

SECTION 5

ANALYSIS OF DUGWAY B 502 TRIALS

5.1 DESCRIPTION OF THE TRIALS

Measurement techniques and other features of the B 502 series of field trials conducted at Dugway Proving Ground have been discussed briefly in Section 3.4 and are summarized in Table 3-1. A detailed description of the experimental procedures, the conduct of the trials, and the dosage measurements obtained is available in reports by Vaughan (1965) and by Vaughan and McMullen (1963). The B 502 field program comprised fourteen trials in which FP tracer material was released from L-20 or L-23 aircraft during crosswind traverses upwind from a sampling network. The effective release heights were generally lower than those for the Dallas Tower trials, ranging from about 14 to 126 meters. In five of the fourteen trials, two aircraft were used to make simultaneous releases, at two different heights. One aircraft released green FP at a height of about 125 meters while the second aircraft released yellow FP at a height of 70 meters. In one trial (No. 8), yellow FP was released from a ground-level line source in conjunction with an aerial line-source release of green FP at a height of 120 meters.

5.1.1 Reliability of Ground-Level Dosage Measurements. Ground-level dosage measurements during the B 502 series were made by means of volumetric air samplers in which the tracer was collected on membrane filters. Dosage measurements at heights above ground level were principally based on rotorod collections made on towers and on balloon cables. In twelve of the trials, simultaneous rotorod and membrane-filter dosage measurements are available at three heights at each of three downwind towers. A comparison of the dosages measured by each pair of collectors shows unexpectedly large discrepancies. The results of an analysis of the frequency distributions of the logarithms of the ratios of membrane filter (M) and rotorod (RR) dosages may be summarized by the following probability statements: for the combined distribution of both green and yellow FP (79 pairs),

$$\Pr\left\{0.16 \le D_M/D_{RR} \le 3.01\right\} = 0.95, \; N = 79$$

and

$$\Pr\left\{0.59 \le \overline{D_M/D_{RR}} \le 0.82\right\} = 0.95 \quad ,$$

where the overbar denotes the geometric mean value of the ratio. The rotorod dosages are adjusted for a collection efficiency of about 60 percent. The B 502 data are not adequate for determining the cause of the large differences between the rotorod and membrane-filter measurements reflected in these probability statements. The possibility that the membrane-filter measurements, and thus the B 502 ground-level dosages, contain large random errors seriously limits the confidence that can be placed in the measured ground-level profiles.

5.1.2 Terrain Features and Mesoscale Circulations. The terrain features associated with the B 502 series are quite different from those prevailing in the vicinity of the Dallas Tower. The B 502 trials were conducted over a flat desert surface with a sparse vegetative cover consisting of small desert plants and bushes. The sampling network was located in a broad valley bordered on the east and west by mountain ranges. The mean elevation of the ridge lines is about 1.5 kilometers above the valley floor.

In the B 502 series, tracer releases were made when the general direction of the air flow was along the major axis of the valley. However, it should be pointed out that the climatic regime and terrain features at this field site are ideally suited to the development of important local wind circulations, especially in the presence of fair weather and light gradient winds (see Barr and Tweedy, 1967). At night under these conditions, strong radiational temperature inversions form in the surface layer, and the winds near ground level are likely to be almost completely decoupled from the flow at higher levels. Also, the low-level wind patterns exhibit large space and time variations which result in very erratic and unpredictable downwind transport of tracer clouds (see Section 5.2).

5.2 CLASSIFICATION OF B 502 TRIALS

Classification of individual trials in the B 502 series follows the procedure used in the analysis of the Dallas Tower Trials (see Section 4.1). Table 5-1 shows the grouping of the trials into four basic categories defined by the wind and temperature structure in the layer between release height and ground level. Entries in the body of Table 5-1 present pertinent meteorological and source parameters as well as selected features of the ground-level dosage profiles associated with each trial. Since no measurements of the wind elevation angle or vertical intensity of turbulence are available for this series of trials, the GCA model can be used only for predictions of the maximum ground-level dosage D_{max}. The mean of the observed distances to the maximum dosage x_{max}obs is used for the predicted value of x_{max} in Column 9 for all cases. In Column 10, x_{max}pred is the value calculated by Vaughan (1965) using the Metronics heat-flux model.

TABLE 5-1

SUMMARY OF DUGWAY B 502 FIELD TRIALS

1	2	3	4	5	6	7	8	9	10	11	12
Stability Category	Trial Numbers	h (Effective) (m)	$\bar{u}^{(2)}$ (m sec^{-1})	$\bar{u}_{2m}$ (m sec^{-1})	ΔT ($T_h - T_{2m}$) (C)	H (m)	$x_{max}obs$ (km)	$x_{max}obs/x_{max}pred$ (3)	$x_{max}obs/x_{max}pred$ (2)	$D_{max}obs/D_{max}pred$ (1)	$D_{max}obs/D_{max}pred$ (2)
I											
Release in near-	B-2Y	126	8.7	8.1	-0.3		3.2	1.06	0.30	0.66	0.70
neutral layer	B-5Y	25	10.5	5.6	+0.2		1.2	0.39	0.19	1.85	3.49
$\frac{\partial T}{\partial z} < 0$	B-8G	109	5.8	4.5	-0.5		11.3	3.73	0.33	1.34	1.73
with no inversion.	B-9Y	63	9.8	7.5	-0.8		3.2	1.06	5.00	1.11	0.56
	B-9G	118	11.1	7.5	-1.4		3.2	1.06	1.53	1.80	0.92
	B-10Y	56	4.5	2.6	-1.1		0.4	0.13	0.62	2.03	3.55
	B-10G	114	4.5	2.6	-1.7		0.3	0.13	0.15	0.73	1.28
	B-12Y	63	9.8	4.9	0.0		1.2	0.39	0.28	1.20	1.06
	B-14Y	109	9.4	8.0			3.2	1.05	0.29	0.46	0.55
II											
Release in stable	B-1Y	63	8.8	4.2	+3.3	150**	9.6	0.20	0.23	0.79	1.67
layer	B-3Y	22	6.0	2.5	+3.6	150**	6.4	1.34	2.10	1.36	3.28
$\frac{\partial T}{\partial z} > 0$	B-4Y	65	9.5	3.0	+3.9	90**	6.4	1.35	0.60	0.56	1.77
beneath inversion cap.	B-11Y	14	5.2	1.6	+4.0	50	0.4	0.08	4.00	1.37	4.52
	B-13Y	1	8.6	7.1			9.5	2.01	60.00	0.74	0.90
III											
Release above inversion	B-6Y	63	9.4	2.4	+5.5	45	17.6		*	0.08	0.34
cap	B-6G	109	9.4	2.4	+5.5	45			*	0*	0*
	B-11G	123	5.2	1.6	+5.5	90	14.5		1.07	0.06	0.21
IV											
Light wind cases	B-7G	109	1.7	2.1					0.56	1.70	1.37
	B-7Y	56	1.7	2.1					0.56	0.64	0.51

*No measured ground-level dosages.

**Height estimated from aircraft data.

(1) $DU/Q = 0.485/h$

(2) From Table 3, p. 58, Metronics Assoc. Tech. Rpt. No. 177.

(3) $x_{max}pred = \overline{x_{max}obs}$

Analysis of dosage measurements made during the B 502 program, and during other trials at Dugway Proving Ground, on a 100-meter tower located about 90 meters downwind from the release line showed the mean effective release height for thirty eight trials to be 11.4 meters below the height of the aircraft. Several types of aircraft, including the L-23 and FJ4, were used but no significant differences due to type of aircraft were found. A depression of 11.4 meters corresponds to a mean downward velocity of about 1 meter per second, which agrees closely with values calculated from the expression (Metronics Associates, 1964):

$$w = Wg/\rho aV \quad , \qquad (5\text{-}1)$$

where

w = initial downward velocity (ft sec^{-1})

W = aircraft weight (lbs)

g = gravitational acceleration (ft sec^{-2})

a = wake cross-section area (ft^2)

V = true air speed of the aircraft (ft sec^{-1})

and ρ = air density (lb ft^{-3}).

Maximum dosages were calculated by Metronics using both the actual and effective release heights. Significant differences were found only for the lowest release heights, which were from 14 to 30 meters.

Dosage measurements made on the 100-meter tower during the B 502 series also were used to estimate the initial vertical cloud dimensions σ_{z_o}. The average value of σ_{z_o} observed during ten trials was 5.8 meters. These estimates were used by Metronics in calculating predicted values of x_{max} from the expression

$$x_{max} = \frac{\bar{u}}{2K}\left[(h)^2 - (\sigma_{z_o})^2\right] \quad , \qquad (5\text{-}2)$$

where K is the vertical diffusivity and h is the effective release height. These values of x_{max} have been used to form the ratios shown in Column 10 of Table 5-1.

According to Vaughan (1965), only three of the fourteen trials in the B 502 series are considered successful with respect to satisfying the stability, wind conditions, and dosage-measurement objectives of the field experiments. Seven trials are regarded as only partially successful either because of variable wind conditions, which precluded adequate measurements over the entire downwind sampling network (Trials 1, 2, 3, 8, 10, and 14), or because of dosage sampling deficiencies (Trials 1, 2, 3, 13, and 14). Finally, four trials were considered unsuccessful due to poor cloud trajectories (Trials 7, 9, 11, and 12).

5.3 DISCUSSION OF GROUND-LEVEL DOSAGE PROFILE

As mentioned in Section 5.2, predicted or model estimates of ground-level dosage parameters are limited due to the absence of turbulence measurements in the B 502 series. This precludes the use of the GCA model except for estimates of D_{max}, which are calculated from a formula common to all Gaussian plume models. Predicted values for the distance to the maximum are available from the Metronics heat-flux model and from the mean of all the observed maximum distances. The following discussion is based on the entries in Table 5-1 and the summary statistics for Categories I and II of this table, which are shown in Table 5-2.

5.3.1 Comparison of Observed and Predicted Maximum Dosage. Observed and predicted values of D_{max} are compared by means of the ratio D_{max}obs/D_{max}pred. Differences between the predicted values used in calculating the ratios presented in Columns 11 and 12 of Table 5-1 arise from the use of different mean wind speeds in the Gaussian model. The ratios in Column 11 are based on the mean wind speed at 2 meters (GCA model), and the ratios reported by Metronics in Column 12 are based on the average wind speeds listed in Column 4. The use of a low-level mean wind speed reduces the large values reported in Column 12 for Trials B-5Y, B-10Y, B-3Y, and B-11Y. The mean, median, and standard deviation of the ratio distributions for Categories I and II are presented in Table 5-2.

The small values of the ratio reported in Category III reflect the very small amount of material that was able to penetrate the inversion and reach ground level. The two releases made in Trial 6 are of particular interest. The effective height of release for the yellow pigment was only 18 meters above the inversion cap located at 45 meters, and small amounts of pigment reached ground level. In contrast, the effective height of release for the green pigment was 64 meters above the inversion cap. In this case no material was measured at ground level.

Prediction of D_{max} for the light wind releases was good, but the variable winds present caused irregularities in the dosage profile.

5.3.2 Comparison of Observed and Predicted Distance to Maximum Dosage. Comparison of the observed distance to maximum ground-level dosage with the distance predicted by the Metronics model is made by means of the ratio x_{max}obs/x_{max}pred. For Category I the mean value of the ratio is 0.97 and the standard deviation of its distribution is 1.57. The mean is strongly influenced by Trial B-9Y, however, and a more significant statistic may be the median value of 0.30 which indicates that the Metronics model tends to overestimate x_{max}. Values of the ratio for Category II show extreme variation, ranging from 0.23 to 60.00. The only ratio reported for the trials of Category III is based on a ground-level profile of small measured dosages and no well defined maximum. For the two releases of Category IV the observed value of x_{max} was 56 percent of the predicted value.

TABLE 5-2

SUMMARY OF OBSERVED AND PREDICTED GROUND-LEVEL DOSAGE PROFILES FOR DUGWAY B 502 FIELD TRIALS, CATEGORIES I AND II

	$\frac{x_{max}obs}{x_{max}pred}$		$\frac{D_{max}obs}{D_{max}pred}$	
CATEGORY I	Metronics	Data Mean*	GCA	Metronics
N	9	9	9	9
Mean	0.97	1.00	1.24	1.54
Median	0.30	1.05	1.20	1.06
Standard Deviation	1.57	1.10	0.56	1.18
CATEGORY II				
N	5	5	5	5
Mean	13.39	1.00	0.96	2.43
Median	2.10	1.34	0.79	1.77
Standard Deviation	26.12	0.83	0.38	1.46

*$x_{max}pred = \overline{x_{max}obs}$

In contrast to the Dallas Tower trials, the ratios of x_{max}/h show a large range of values and differ in the mean by a factor of 6.5 between Categories I and II. Values of these ratios range from 3 to 104 for the trials of Category I, and from 29 to 561 for the trials of Category II. Mean values for these two categories are 35 and 226 respectively.

5.4 SUMMARY OF THE B 502 SERIES ANALYSIS

The results of the B 502 series support the classification system used in analyzing the elevated line source trials and in summarizing the meteorological restrictions which apply to the use of the elevated release. In addition, several trials of the B 502 series illustrate erratic and unpredictable downwind transport of the tracer clouds associated with local wind circuations. Further, it appears that significant penetration through an inversion cap to ground level may occur from release heights of about 50 meters or less.

SECTION 6

SUMMARY OF RESULTS AND CONCLUSIONS

Current procedures for modeling elevated line-source releases have been examined with respect to existing knowledge of low-level atmospheric structure and measured dosage patterns. Comparisons of existing prediction techniques show the principal differences to be in the method used to specify the rate of vertical expansion of the cloud, and in the extent to which source dimensions, multiple reflections, and edge effects have been incorporated into the basic Gaussian model.

An examination of available field data and an intensive analysis of measurements made during the Dallas Tower trials and the B 502 series at Dugway Proving Ground clearly indicates that the elevated line-source technique is most effective when the releases are made at heights of the order of 100 meters above relatively smooth terrain in the presence of moderate or strong wind speeds and near-neutral thermal stratification. Efficient atmospheric dispersal and transport mechanisms require a high degree of coupling between the air flow at release height and the flow at ground level. This precludes the presence of moderate or strong temperature inversions located either near ground level or at any height intermediate between the release height and the ground. A sufficient degree of coupling is indicated by a mean wind speed near the ground of at least 3 meters per second and a wind speed at the effective release height of at least 10 meters per second. Also, the vertical intensity of turbulence at release height must exceed 0.01. The rapid upward transport of airborne material which is associated with convective circulations precludes effective downwind transport during periods of unstable thermal stratification. In areas where the terrain is not smooth, the ground dosage pattern will reflect obstacle flow. Use of the elevated line source over irregular terrain or near major surface discontinuities (coastal areas) requires a detailed knowledge of mesoscale circulations.

An analysis of the Dallas Tower trials shows that ground-level dosage profiles can be predicted over rolling terrain with fair success by existing models if releases are made in a near-neutral layer or in a stable layer beneath the inversion cap provided light wind situations are avoided. Under these conditions observed dosages during the Dallas trials were about 65 percent of the dosages predicted by the GCA model and about 125 percent of the values predicted by the MRI model. This

difference is largely due to the use of different mean wind speeds in the two models. The dosage profiles observed along the direction of the mean wind frequently showed large irregularities. Similarly, considerable variation was found in the crosswind direction; values of the crosswind variability coefficient $\sigma_D/\bar{D}$ ranged from 0.25 to 1.82. The distance at which the maximum dosage occurred varied from about 100 to 300 times the release height. This distance was predicted with only fair precision by both models. The median value of the ratio $x_{max}obs/x_{max}pred$ was 1.12 for the MRI model and 0.95 for the GCA model. The ranges for this ratio were 0.32 to 4.20 for the MRI model and 0.55 to 4.08 for the GCA model.

Both the Dallas Tower trials and the B 502 series confirm that little or no material reaches ground level within 40 to 50 kilometers of aerial releases made above strong temperature inversions. It is unlikely that penetration of such an inversion by appreciable amounts of material can be accomplished other than by very low releases (less than 50 meters) aided by aircraft wake turbulence. The effect of the aircraft on the released cloud has been shown to be twofold. First, there is a downward displacement of the aerosol cloud. Thirty-eight releases carried out at Dugway Proving Ground with L-23 and FJ4 aircraft gave an average downward displacement between the release line and a tower 91 meters downwind of about 11.4 meters. Second, the vortex field behind the releasing aircraft results in an initial rapid growth of the cloud which is independent of the diffusing power of the ambient air. The expected vertical dimension of the wake-vortex field is given by 1.33b where b is the wingspan of the aircraft. The use of the elevated line source during inversion conditions is usually further complicated by the presence of light and highly variable winds which result in erratic and unpredictable downwind transport of the tracer cloud. The B 502 series illustrates the difficulties encountered in predicting cloud trajectories when the air flow at ground level is dominated by local wind circulations and is almost completely decoupled from the wind flow aloft.

REFERENCES

Barad, M. L., and G. R. Hilst, 1951: A recomputation and extension of parameters involved in Sutton's diffusion hypothesis. R.N. HW-21415. General Electric Nucleonics Dept., Richland, Wash.

Barr, S., and D. Tweedy, 1966: Empirical studies of mesoscale circulations. GCA Tech. Rpt.No.66-11-G, Contract No. DA-42-007-AMC-120(R).

Bierly, E. W., and E. W. Hewson, 1962: Some restrictive meteorological conditions to be considered in the design of stacks. J. App. Meteor. 383-390.

Cramer, H. E., and F. A. Record, 1953: The variation with height of the vertical flux of heat and momentum. J. Meteor, 10, 219-226.

Cramer, H. E., G. M. DeSanto, R. K. Dumbauld, P. Morgenstern, and R. N. Swanson, 1964: Meteorological prediction techniques and data system, Final Report, Contract No. DA-42-007-CML-552. GCA Tech. Rpt. No. 64-3-G, 251.

Cramer, H. E., G. M. DeSanto, R. K. Dumbauld, B. R. Greene, P. Morgenstern, and R. N. Swanson, 1965: CB field test prediction trials, Final Report, Contract No. DA-42-007-AMC-36(R), GCA Tech. Rpt. No. 65-9-G, 184.

Elliott, W. P., and M. L. Barad, 1964: Operational prediction of diffusion downwind from line sources. AFCRL-64-163, 56.

Haugen, D. A., M. L. Barad, and P. Antanaitis, 1961: Values of parameters appearing in Sutton's diffusion models. J. Meteor., 18, 368-372.

Hay, J. S., and F. Pasquill, 1959: Diffusion from a continuous source in relation to the spectrum and scale of turbulence. Adv. Geophysics, 6, Academic Press. 345-365.

Hinze, J. O., 1959: Turbulence, McGraw-Hill, New York.

Lettau, H. H., and B. Davidson (ed), 1957: Exploring the atmosphere's first mile. Vol. II, Pergamon Press, London, England, 578.

Lumley, J. L., and H. A. Panofsky, 1964: The Structure of Atmospheric Turbulence. Interscience Publishers, John Wiley and Sons, New York, 239.

MacCready, P. B., Jr., T. B. Smith, and M. A. Wolf, 1961: Vertical diffusion from a low altitude line source. Dallas Tower Studies, Vol. I. Final Report to U. S. Army Chemical Corps Dugway Proving Ground under Contract DA-42-007-CML-504, Meteorology Research, Inc., Altadena, California, 65.

MacCready, P. B., Jr., T. B. Smith, and M. A. Wolf, 1961: Vertical diffusion from a low altitude line source. Dallas Tower Studies, Vol. II. Final Report to U. S. Army Chemical Corps Dugway Proving Ground under Contract DA-42-007-CML-504, Meteorology Research, Inc., Altadena, California, 85.

Milly, G. H., 1958: Atmospheric diffusion and generalized munition expenditures. ORG Study NR 17, U. S. Army Chemical Corps, 290.

Mitcham, W. S., and K. H. Jehn, 1964: Operation and performance of the Cedar Hill meteorological tower facility. Final Report, Contract No. AF19(628)-2459, University of Texas, 43.

Palmer, V. S., and A. R. Craw, 1962: A computational aid for line source calculations. Tech. Mem. 3-17, U. S. Army Chemical Corps Research and Development Command Biological Laboratories, Fort Detrick, Md., 27.

Pasquill, F., 1962: Atmospheric Diffusion. D. Van Nostrand Co., Ltd., London, 297.

Smith, F. B., and J. S. Hay, 1961: The expansion of clusters of particles in the atmosphere. Quart. J. Rog. Meteor. Soc., 87, 82-101.

Smith, T. B. and M. A. Wolf, 1961: Further analysis of windsoc data. Final Report to U. S. Army Chemical Corps Dugway Proving Ground under Contract DA-42-007-CML-504, 42.

Smith, T. B., and M. A. Wolf, 1963: Vertical diffusion from an elevated line source over a variety of terrains, Part A, Final Report to Dugway Proving Ground under Contract DA-42-007-CML-545, 67.

Smith, T. B., and P. J. MacCready, Jr., 1963: Aircraft wakes and diffusion enhancement, Part B, Final Report to Dugway Proving Ground under Contract DA-42-007-CML-545, 14.

Sutton, O. G., 1953: Micrometeorology. McGraw-Hill, New York.

Swinbank, W. C., 1955: An experimental study of eddy transports in the lower atmosphere. C.S.I.R.O. Div. Met. Phys., Tech. Pap. No. 2, Melbourne.

Swinbank, W. C., 1964: The exponential wind profile. Quart. J. R. Meteor. Soc., 90, 119.

Taylor, G. I., 1938: The spectrum of turbulence. Proc. Roy. Soc., A 164, 476.

Vaughan, L. M., and R. W. McMullan, 1963: Intermediate - scale aerosol cloud travel and diffusion from low-level aerial line releases. Tech. Rpt. No. 97 under U. S. Army Chemical Corps Contract DA-42-007-CML-543, 81.

Waldron, A. W., Jr., 1963: The application of an elevated line source diffusion formula, J. Appl. Meteor., 2, 740-746.

[illegible]

[illegible]

[illegible] [illegible]. 1961. [illegible]

[illegible] 1962. [illegible]

[illegible] 1961.

[illegible]

[illegible]

Smith, [illegible] 1953. [illegible]

Smith, T. S., and P. [illegible], Jr. [illegible]

[illegible], A. C., 1951. [illegible]

[illegible], V. C., 1955. [illegible]

APPENDIX

XIV

519279

TECHNICAL REPORT No. 117

Further Analysis Of Intermediate-Scale Aerosol Cloud Travel And Diffusion Data From Low-Level Aerial Line Releases

L. M. VAUGHAN

2 June 1965

Research and Development Contract
DA-42-007-AMC-21(R)

METRONICS

AEROSOL LABORATORY

METRONICS ASSOCIATES, INC.
STANFORD INDUSTRIAL PARK
PALO ALTO, CALIFORNIA

519279

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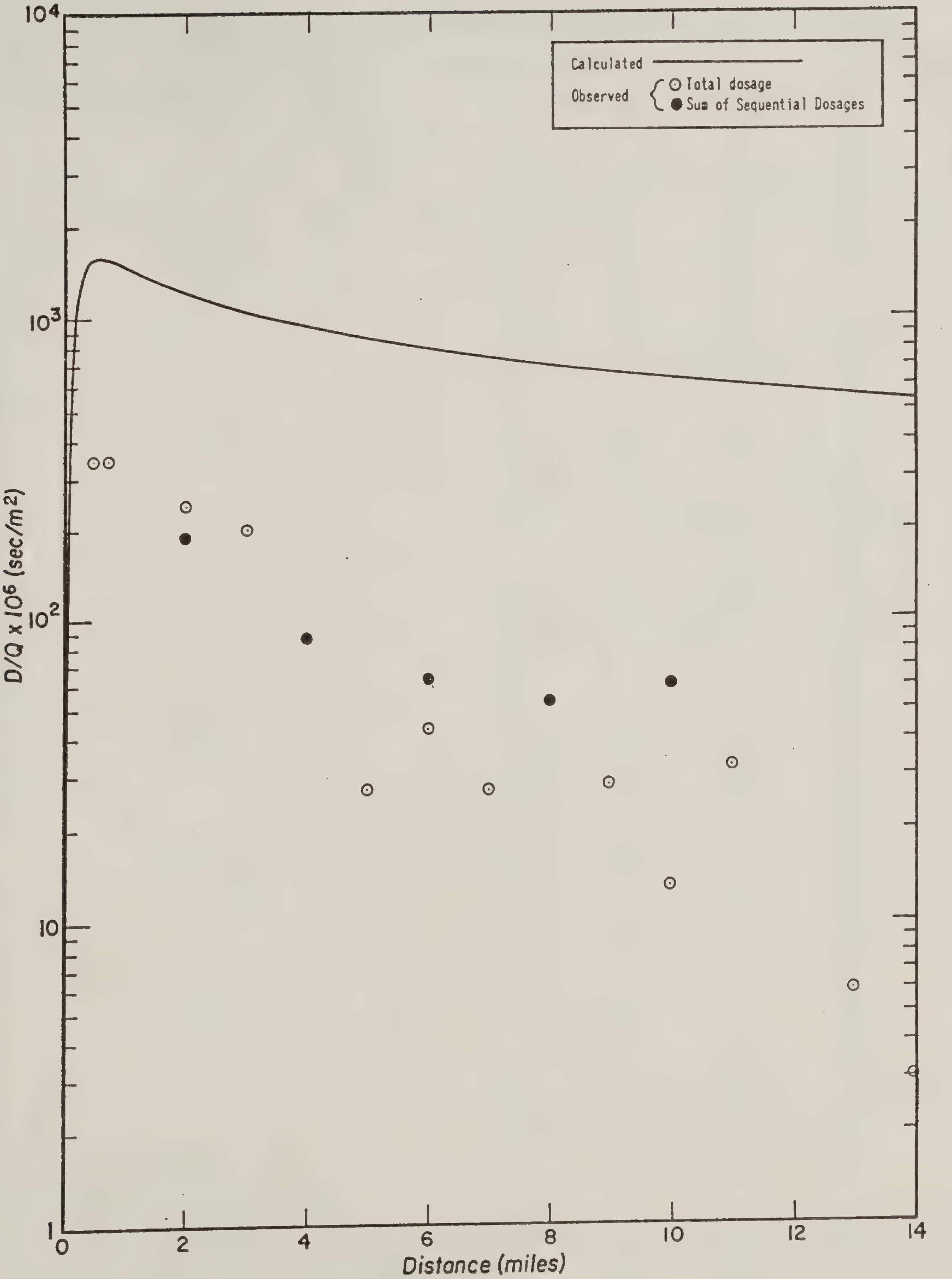

Fig. 44--Trial B10Y: Ground-level dosage per unit source vs distance downwind for yellow FP release at 225 feet.

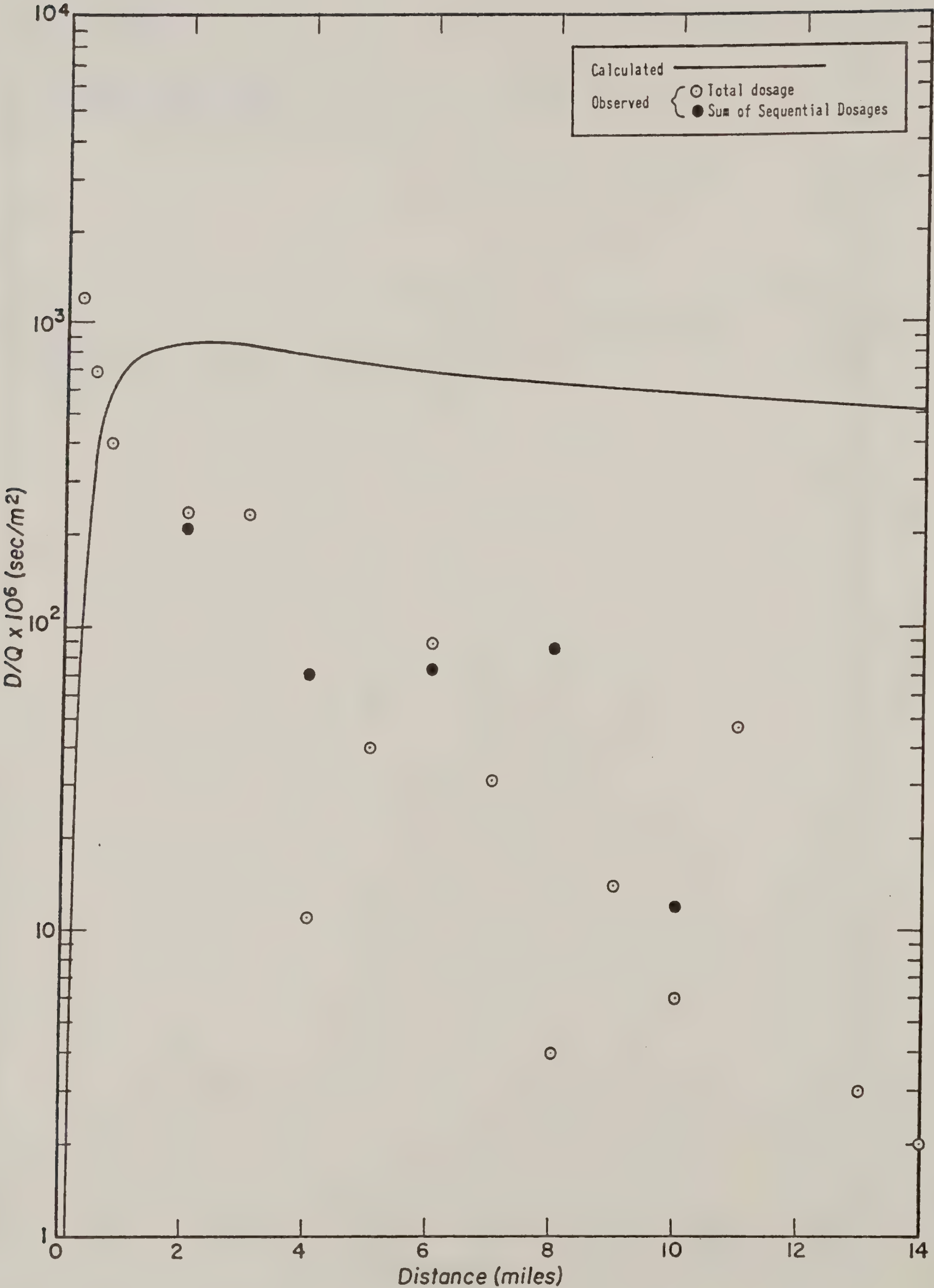

Fig. 45--Trial B10G: Ground-level dosage per unit source vs distance downwind for green FP release at 415 feet.

Table 4

MAXIMUM GROUND-LEVEL DOSAGES PER UNIT SOURCE AND DISTANCE TO MAXIMUM AND 1/10th MAXIMUM FOR AERIAL LINE RELEASES AT DUGWAY PROVING GROUND

Release Height (ft.)	Range (ft.)	Stability*	Wind Speed (mph) 150 ft.	Wind Speed (mph) 2m	Test Series	Trial** No.	$(D\ max/Q) \times 10^{-6}$ (sec/m^2)	Distance (miles) max	Distance (miles) 1/10max
100	60-160	Neutral	>15		B502	B5	6,421	0.75	0.2
		Stable	>15	>10	B502	B13Y	2,984	6	0.3
					B589	A4	4,610	1	0.5
					B589	B10	10,943	0.5	0.1
					Mean		6,179	2.5	0.3
		Stable	5-15		B589	B9	11,860	0.75	0.1
					B589	B11	13,070	0.25	0.1
					Mean		12,465	0.5	0.1
		Very Stable	5-15		B502	A5	2,200	7	4.8
					B502	B3	11,970	4	3.2
					B502	B11Y	29,732	4	0.1
					Mean		14,634	5.0	2.7
250	200-255	Unstable	<5		B502	B7Y	2,630	0.5	0.1
		Neutral	>15		B502	B9Y	1,140	2	0.8
					B502	B12Y	1,882	0.75	0.6
					Mean		1,511	1.4	0.7
		Neutral	5-15		B502	B10Y	6,770	0.25	0.1
		Stable	>15	>6	B502	B1	1,452	6	0.4
		Very Stable	>15	>6	B502	B4	1,388	4	2.6
		Very Stable	>15	>3-6	B502	B6Y	+	>15	10++
		Very Stable	5-15	3-6	B502	A3	7,750	14	7.7
					B502	A6	11,680	8	6.5
					Mean		9,715	11	7.1
400	400-500	Unstable	<5		B502	B7G	3,045	2	0.6
		Unstable	>15		B502	B14Y	258	2	0.6
		Neutral	>15		B502	A2	169	4	2.0
					B502	B2	313	2	0.5
					B502	B12G	1,290	4	---
					Mean		591	3.3	1.2

Table 4 Continued

Release Height (ft.)	Range (ft.)	Stability*	Wind Speed (mph) 150 ft.	2m	Test Series	Trial No.	(D max/Q) x 10^{-6} (sec/m^2)	Distance (miles) max	1/10max
400	400-500	Neutral	5-15		B502	B10G	1,200	0.25	0.2
		Stable	>15	<10	B502	B8G	1,330	7	3.1
		Very Stable	>15	<10	B502	B6G	+	>15	>15

* $T_{91m} - T_{2m}$ { < - 2°F Unstable; -2 to 0°F Neutral; 0 to 8°F Stable; >8°F Very Stable

** Y = yellow FP ; G = green FP

\+ Maximum not reached within sampling array

++ Estimated from ratio of ground-level dosage to peak dosage aloft.

to reach maximum D/Q will generally be greater than 10 miles for very stable conditions.

Aerial releases at 400 ft. and higher will produce D/Q values of 1000 x 10^{-6} sec/m^2 or larger under unstable and neutral conditions for wind speeds less than 15 mph. Under stable conditions the aerosol may not reach the ground for many miles.

2. Comparison with other test areas.

The only comparable data at other locations were obtained by Meteorology Research, Inc., at Dallas and Corpus Christi, Texas and Cushing, Oklahoma. (6) The lower releases at Dallas were made at heights of 380 and 450 ft. above the base of a 1400 ft. T V tower and those at Corpus Christi and Oklahoma were about 500 ft. above the terrain. The Corpus Christi test site was very flat, like Dugway. However, the releases were off-shore and the climatological situation was quite different. The Dallas and Oklahoma sites were in rolling terrain giving a larger degree of mechanical turbulence due to the roughness.

The trials at Dugway included a wider range of atmospheric stability and wind conditions than those at the Texas and Oklahoma sites. However, compari-

Table 8

Vertical Standard Deviation of Dosage for B502B Trials 5, 6 and 8
At Dugway Proving Ground for Various Estimates of β and Length Scale of Turbulence

Trial	Release Height (m)	i_u	i_w	X (miles)	Observed σ_z (m)	ℓ (m)	Calculated σ_z (m) β =4.5	$\beta = 1/2i_w$	$\beta = 1/2i_u$
B5	38	0.0727	0.0208	0	4.9				
				0.5	19.8	7.6	6.1	10.1	6.7
						15.2	6.1	10.7	6.7
						30.5	6.1	10.4	6.7
				2	29.9	7.6	8.8	20.1	11.0
						15.2	9.2	24.7	11.3
						30.5	8.8	26.5	11.0
				6	27.4	7.6	14.9	36.9	18.9
						15.2	18.6	48.8	22.6
						30.5	17.1	60.4	23.8
				10	39.3	7.6	19.5	48.2	24.7
						15.2	23.5	65.3	30.8
						30.5	25.3	83.9	35.1
B6Y	76	0.0516	0.0239	0	3.4				
				0.5	10.0	7.6	4.9	9.5	6.1
						15.2	4.6	9.8	6.1
						30.5	4.3	8.5	5.5
				2	13.4	7.6	8.5	21.0	13.4
						15.2	8.8	25.3	14.6
						30.5	7.6	27.4	14.0
				6	22.9	7.6	16.2	39.0	25.6
						15.2	18.6	51.8	32.0
						30.5	18.6	64.0	36.0
				10	28.4	7.6	22.0	51.8	33.9
						15.2	26.8	70.2	44.2
						30.5	29.0	91.5	53.4

Table 8 (Continued)

Trial	Release Height (m)	i_u	i_w	X (miles)	Observed σ_z (m)	ℓ (m)	Calculated σ_z (m) $\beta = 4.5$	$\beta = 1/2i_w$	$\beta = 1/2i_u$
B8Y	Sfc	0.114	0.0566	0	4.6				
				0.5	9.8	7.6	12.2	16.8	12.2
						15.2	13.1	19.5	13.1
						30.5	13.1	20.4	12.8
				2	15.5	7.6	24.4	36.9	24.1
						15.2	30.5	45.8	30.2
						30.5	35.1	56.7	34.5
				6	34.2	7.6	44.2	62.2	43.3
						15.2	58.6	85.4	58.0
						30.5	74.7	114.4	73.8
				10	49.7	7.6	57.3	84.5	56.4
						15.2	77.8	111.3	77.8
						30.5	103.7	153.7	102.5

APPENDIX

XV

METRONICS

TECHNICAL REPORT
No. 97

Intermediate-Scale Aerosol Cloud Travel And Diffusion From Low-Level Aerial Line Releases

L. M. VAUGHAN
R. W. McMULLEN

30 January 1963

U. S. Army Chemical Corps
Research and Development Contract
DA-42-007-CML-543

AEROSOL LABORATORY

METRONICS ASSOCIATES, INC.
STANFORD INDUSTRIAL PARK
PALO ALTO, CALIFORNIA

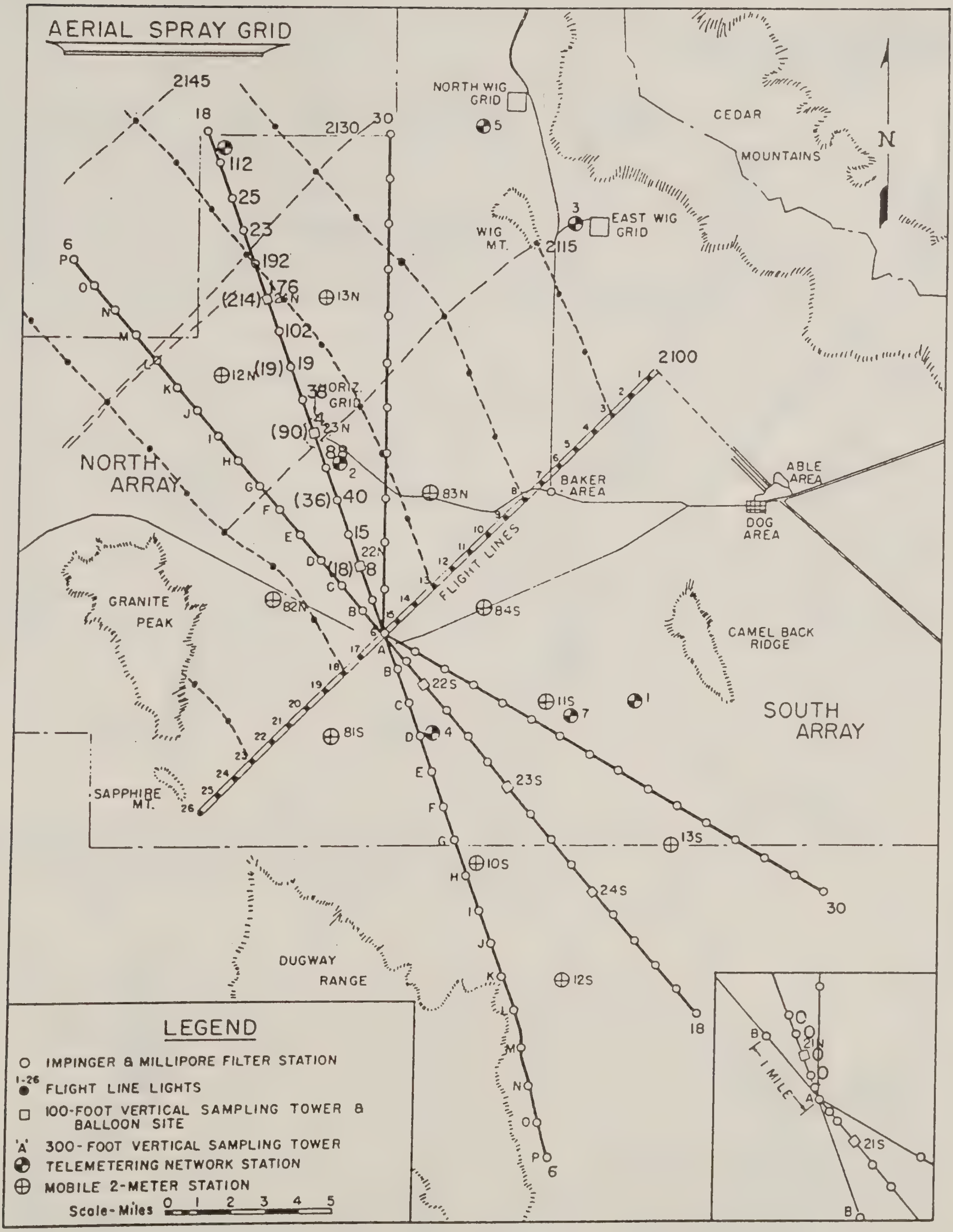

Fig. 15--Trial B-6: Yellow FP recoveries at 5 feet and trajectories calculated from 250-ft winds.

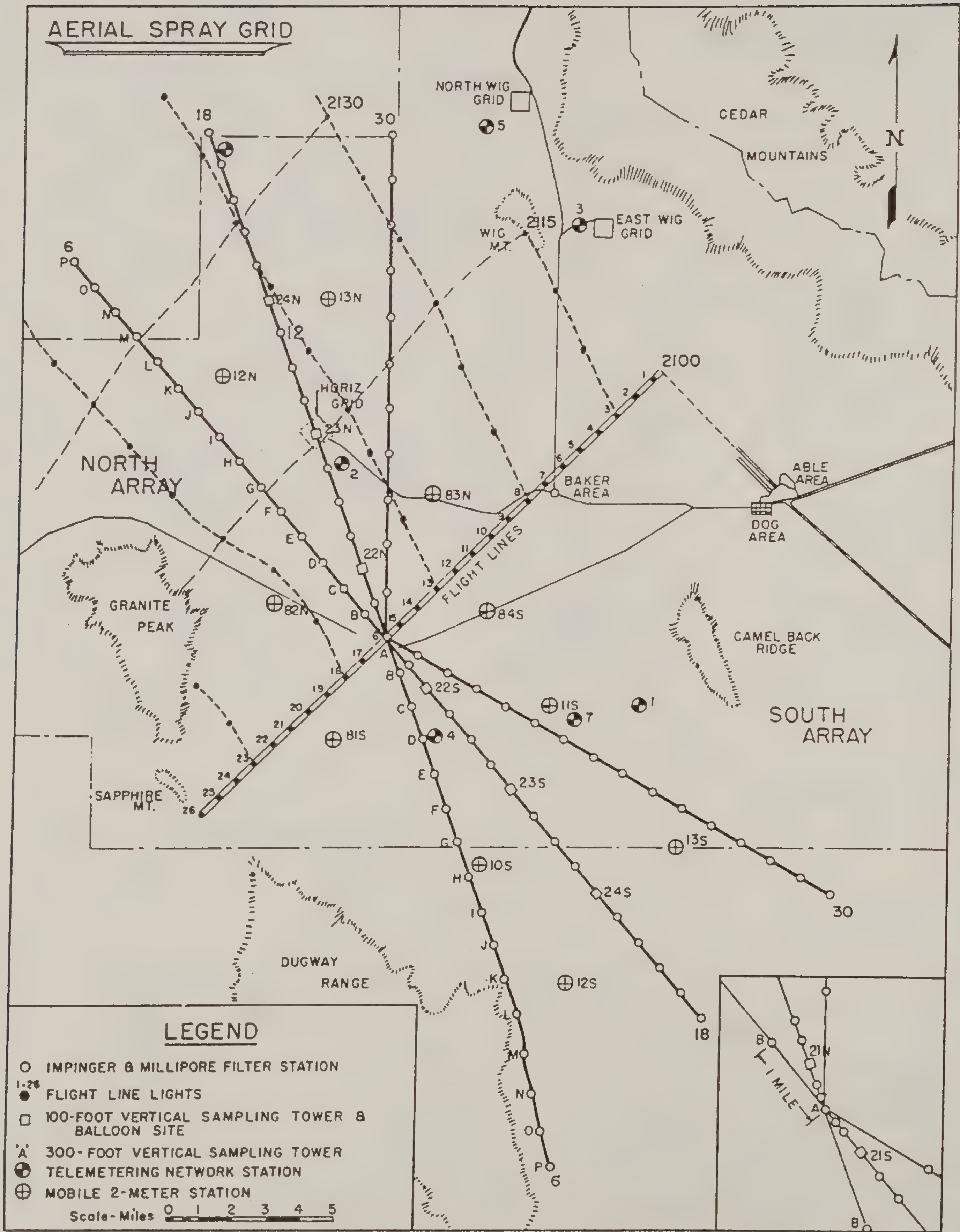

Fig. 16--Trial B-6: Green FP recoveries at 5 feet and trajectories calculated from 480-ft winds.

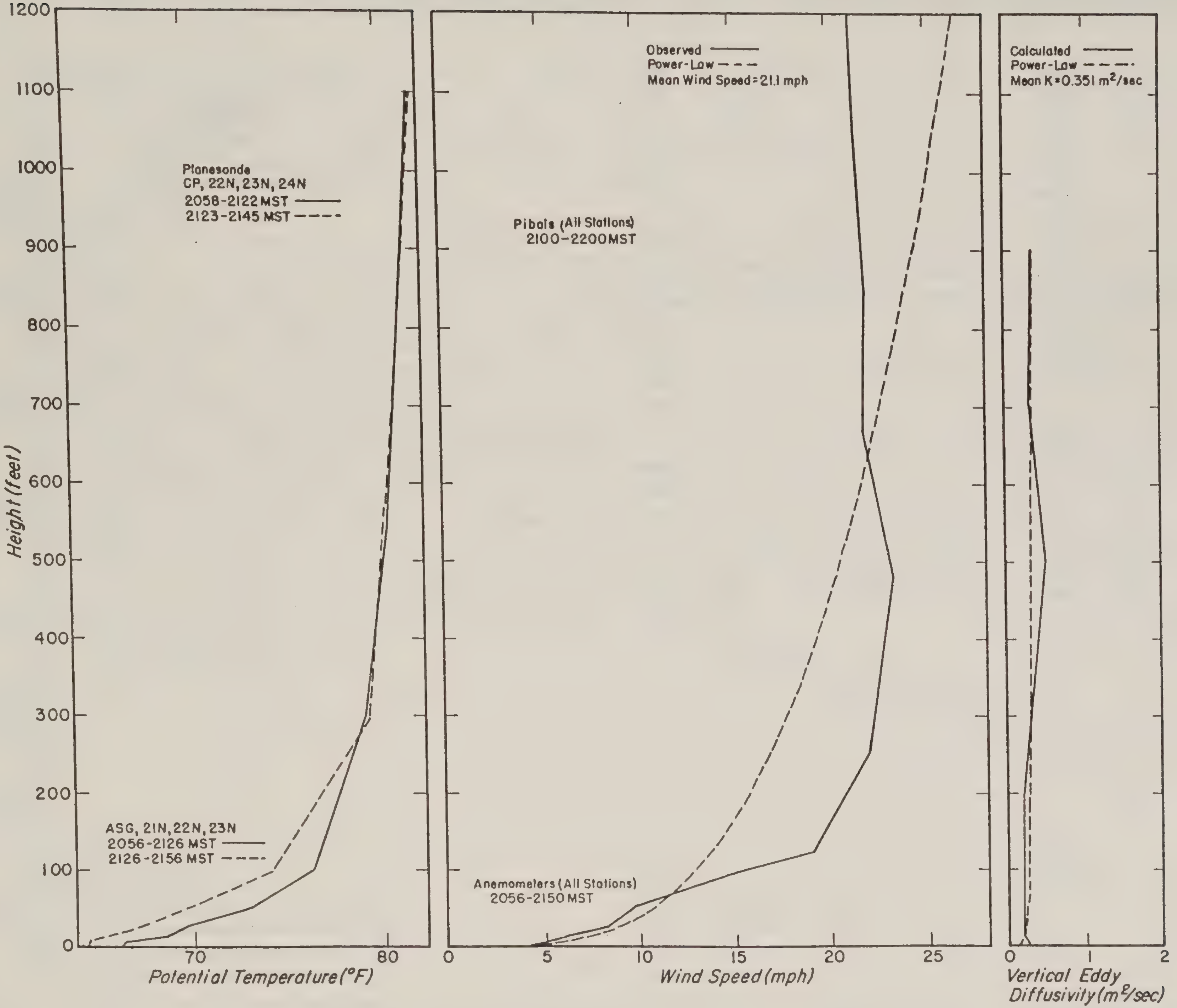

Fig. 33--Trial B-6: a) Potential temperature, b) wind speed and c) vertical eddy diffusivity as functions of height.

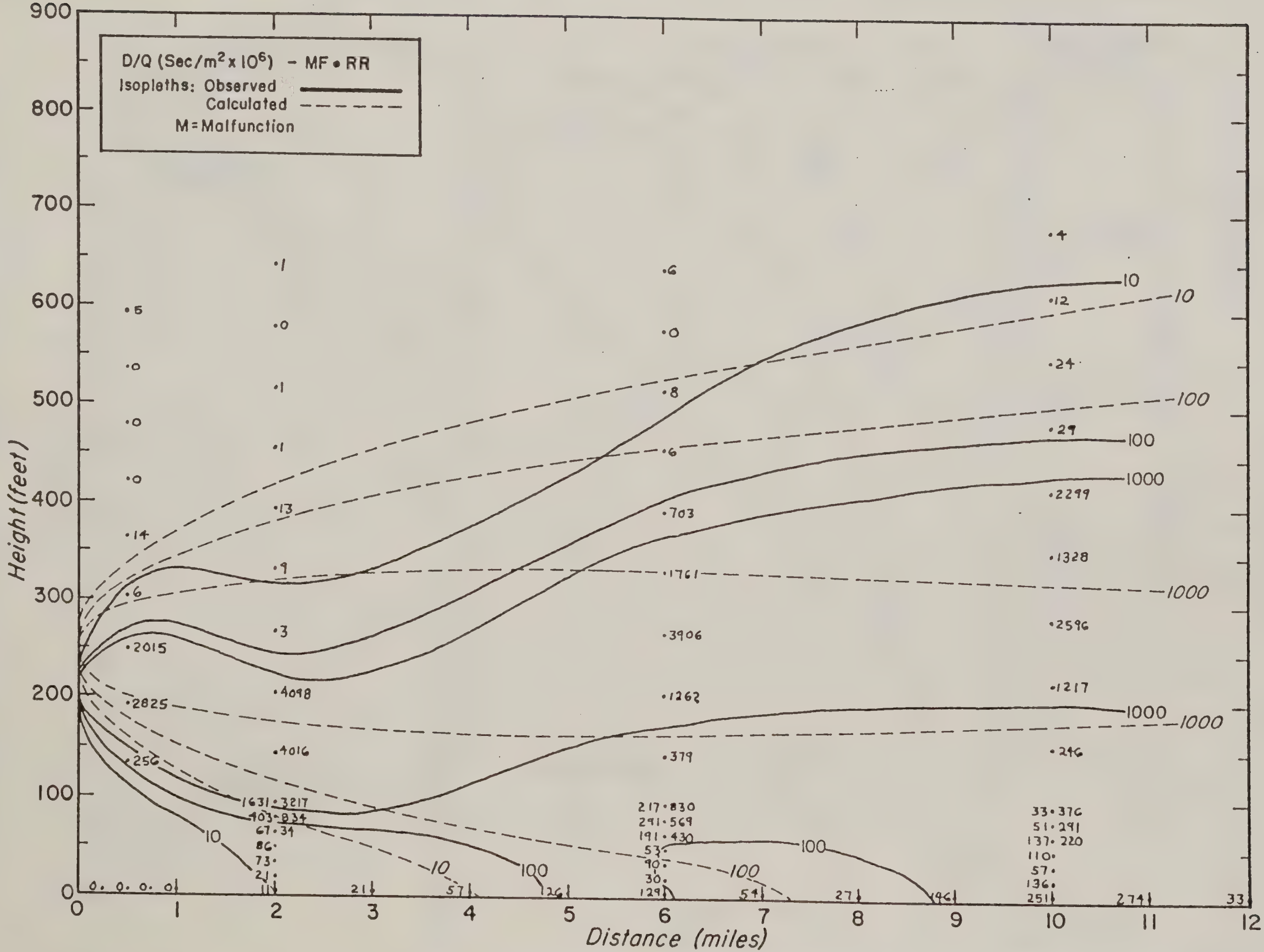

Fig. 34--Trial B-6: Vertical distribution of dosage per unit source strength from yellow FP release at 250 feet. (MF values to left and Rotorod values to right of sampling positions)

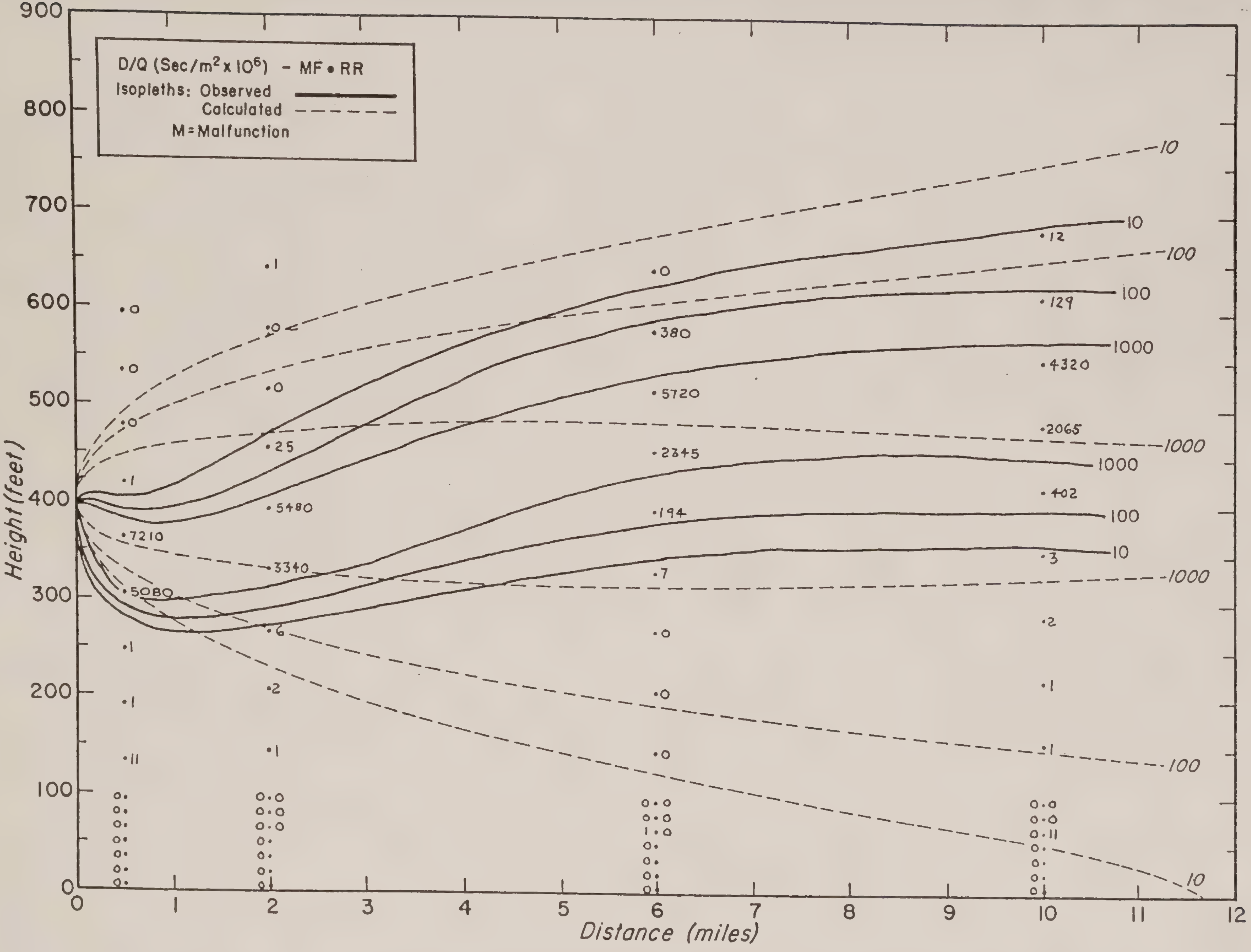

Fig. 35--Trial B-6: Vertical distribution of dosage per unit source strength from green FP release at 400 feet. (MF values to left and Rotorod values to right of sampling positions)

APPENDIX

XVI

I. SUBJECT: DPG Trial Record Number 247, BW 418, Phase A, Trials A-1 and A-2.

II. TITLE: Field Evaluation of a BW Aerial Spray System.

III. LOCATION: An especially designed grid extending northwest from the Downwind Grid into the Great Salt Lake Desert.

IV. DATE AND TIME OF TRIALS:

TRIAL NUMBER	DATE (1958)	FUNCTION TIME (MST)
A-1	18 August	2245
A-2	21 August	2131

V. CONDUCT OF TEST: These trials were conducted in accordance with the procedures outlined in DPG Test Plan BW 418, Phase A, for tower fly-by trials.

VI. DISSEMINATION PROCEDURE: In each trial, two aerial spray tanks (especially developed by North American Aviation, Inc.), one containing 10 gallons of BG slurry and the other 10 gallons of SM slurry, were wing-mounted on a F-100A aircraft. The slurries were disseminated concurrently, at a height of 90 feet (Trial A-1) and 185 feet (Trial A-2) above terrain at true air speeds of 352 and 348 knots, respectively, at a distance of 100 yards upwind from a 300-foot vertical sampling tower located at the vertex of the downwind array (see Fig. 1). A summary of general dissemination data for each trial is given in Table 1.

TABLE 1: General Dissemination Data, BW 418, Trials A-1 and A-2

TRIAL	FLIGHT HEIGHT AT TOWER (Feet above terrain)	TRUE AIR SPEED (Knots)	LENGTH OF DISSEMINATION LINE (Feet)	DISSEMINATION TIME (Seconds)	FLOW RATE (gpm)				AMOUNT OF AGENT DISSEMINATED (Gallons)	
					Pre-set		Calculated			
					BG	SM	BG	SM	BG	SM
A-1	90	352	13,589	22.8	10.2	10.2	11.8	10.2	4.47	3.98
A-2	185	348	12,230	20.8	10.2	10.2	9.5	8.6	3.28	2.97

NOTE: The BG was disseminated from the upwind side of the aircraft in Trial A-1 and from the downwind side of the aircraft in Trial A-2.

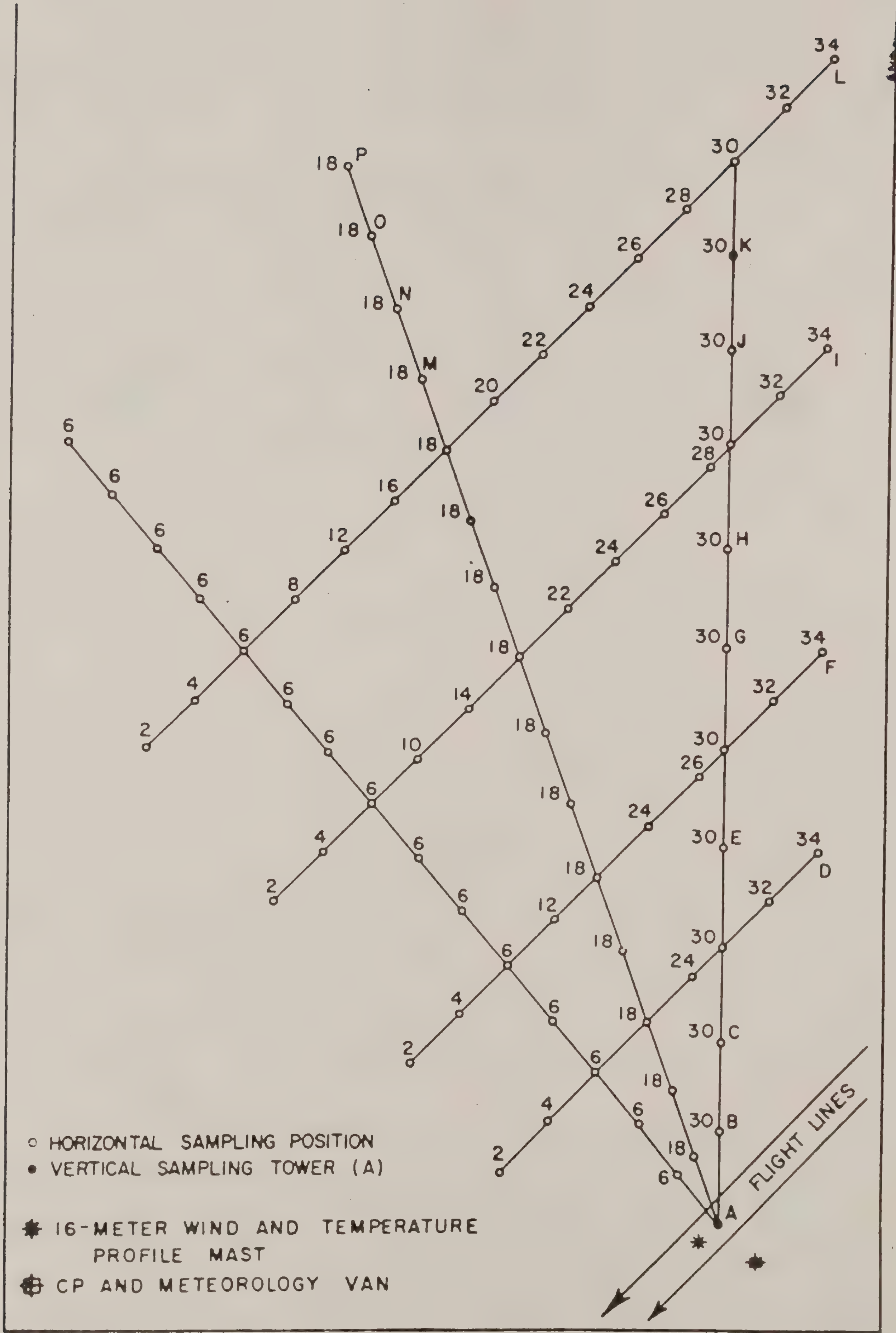

Fig.1.- Diagram showing flight ines, vertical sampling tower, and meteorological stations used in BW 418, Trials A-1 and A-2.

VII. SLURRY CONTROL ASSESSMENT: In each trial, six representative BG and SM slurry samples were withdrawn during the filling of the spray tanks. Each sample was assayed at three or more serial tenfold dilution levels, and the results of these assessments are given in Table 2.

TABLE 2: BG and SM Slurry Control Assessment Data, BW 418, Trials A-1 and A-2

TRIAL NUMBER	ESTIMATED NUMBER OF VIABLE BG AND SM ORGANISMS PER ML OF SLURRY					
	BG			SM		
	Mean	95 Per Cent Confidence Limits ($X 10^9$)		Mean	95 Per Cent Confidence Limits ($X 10^{10}$)	
		lower	upper		lower	upper
A-1	7.86	7.27	8.47	4.80	4.21	5.43
A-2	7.27	6.55	8.03	8.41	7.79	9.05

VIII. SAMPLING DATA: In each trial the sampling was accomplished by means of 59 impingers (AGI 6-15), in series with pre-impingers, mounted at 5-foot intervals on the 300-foot vertical sampling tower (Fig. 1). Because of mechanical difficulties experienced in elevating the samplers to the top of the tower, only 59 of the 60 samplers stipulated in the test plan were used in each trial. Consequently, Sampler Number 2, located 3 feet above terrain, was the first sampling station. Each device was activated shortly before slurry dissemination and was aspirated continuously for a period of 8 to 10 minutes following the initiation of the spray run. The sampling data are presented in Appendix A.

IX. METEOROLOGICAL DATA: A summary of the wind speed and direction, temperature, temperature gradient, and relative humidity data collected during the trials is presented in Appendix B. Four wind speed transmitters were installed at the 100-, 150-, 200-, and 300-foot levels on the vertical sampling tower to provide wind velocity data from 50 to 300 feet above ground. The location of the other meteorological stations is shown in Figure 1. Complete meteorological data are on file at Dugway Proving Ground.

TABLE 1 [illegible] Sampling Data, [illegible], Trial [illegible]

HEIGHT ABOVE GROUND (Feet)	[illegible]		[illegible]	
	Pre-[illegible]	[illegible]	Pre-[illegible]	[illegible]
3	0	0	0	0
8	0	[illegible]	0	0
13	0	182	[illegible]	0
18	225	510	3,195	[illegible]
23	6,312	2,380	5,354	[illegible]
28	10,150	6,2[illegible]	3,[illegible]	[illegible]
33	1[illegible],752	(7,[illegible])*	3,[illegible]	422
38	15,425	3,[illegible]	22,725	1,314
43	17,212	14,[illegible]	8,455	1,[illegible]
48	[illegible],250	20,565	[illegible],455	2,[illegible]
53	21,358	2[illegible],[illegible]	10,225	1,[illegible]
58	24,750	3,550	13,[illegible]	1,164
63	13,375	11,168	1,045	[illegible]
68	14,362	3,282	1,[illegible]	[illegible]
73	15,188	11,[illegible]	5,[illegible]	741
78	[illegible]	[illegible],72[illegible]	[illegible]	35
83	[illegible]	2,[illegible]	[illegible]	35
88	2,[illegible]	1,068	[illegible]	721
93	3,373	1,[illegible]	4,762	[illegible]
98	1,[illegible]	373	256	764
103	[illegible]75	536	[illegible]	35
108	0	1[illegible]	0	[illegible]
113	[illegible]	0	0	[illegible]
118	0	[illegible]	[illegible]	[illegible]
123	[illegible]	[illegible]	[illegible]	[illegible]
128	0	[illegible]	0	0
133	[illegible]	0	0	[illegible]
138	[illegible]	[illegible]	0	[illegible]
143	[illegible]	[illegible]	0	0
148	0	[illegible]	0	0
153	[illegible]	[illegible]	0	[illegible]
158	0	0	0	[illegible]
163	0	0	0	[illegible]
168	0	0	0	[illegible]
173	[illegible]	0	0	[illegible]
178	0	[illegible]	0	[illegible]
183	[illegible]	[illegible]	0	[illegible]
188	[illegible]	0	0	[illegible]
193	0	0	0	[illegible]
2[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

*Numbers in parentheses are interpolated values.

TABLE 2: Sampling Data, BW 418, Trial A-2

HEIGHT ABOVE GROUND (Feet)	ESTIMATED NUMBER OF BG ORGANISMS COLLECTED		ESTIMATED NUMBER OF SM ORGANISMS COLLECTED	
	Pre-impinger	Impinger	Pre-impinger	Impinger
3	0	0	0	0
8	0	0	0	0
13	0	0	0	0
18	0	0	0	0
23	0	0	0	0
28	0	0	0	0
33	0	0	0	0
38	0	0	0	0
43	0	0	0	0
48	0	0	0	0
53	0	0	0	0
58	0	0	0	0
63	0	0	0	0
68	0	0	0	0
73	22	0	0	0
78	22	276	0	0
83	1,271	360	2,284	360
88	1,462	2,614	1,924	2,270
93	1,261	2,353	6,176	3,113
98	2,351	2,646	9,698	9,306
103	5,404	6,055	27,675	8,339
108	7,706	8,050	37,238	30,751
113	5,561	10,149	45,000	29,768
118	6,041	14,183	34,312	20,145
123	16,200	20,382	8,258	10,354
128	8,675	14,266	21,600	11,904
133	1,429	4,523	3,375	3,608
138	3,848	3,081	7,875	(3,824)*
143	1,654	5,571	4,860	5,190
148	7,582	2,590	10,125	7,992
153	(3,825)	275	4,680	2,106
158	68	(318)	11,250	(2,178)
163	0	366	6,300	2,654
168	68	0	0	0
173	0	0	0	0
178	0	0	0	0
183	0	0	0	0
188	0	0	0	0
193	0	0	0	0
↓	↓	↓	↓	↓
293	0	0	0	0

*Numbers in parentheses are interpolated values.

APPENDIX

XVII

HEADQUARTERS
U.S. ARMY CHEMICAL CORPS PROVING GROUND
DUGWAY PROVING GROUND
Dugway, Utah

CMLRD-DU-GTB

SUBJECT: Dugway Proving Ground Trial Record DPGTR 248, BW 418, Phase A, Trials A-3 and A-4

TO: See Distribution List

I. TITLE: Field Evaluation of a BW Aerial Spray System, BW 418, Phase A.

II. AUTHORITY: The authority for this test is contained in Letter CMLRD-BW-12, subject: Request for Aerial Spray Test Program (U), dated 3 April 1958. Confidential. This project was funded under Dugway Job Order Number 1-30-19.

III. LOCATION: An especially designed grid extending northwest from the Downwind Grid into the Great Salt Lake Desert.

IV. GENERAL TEST CONDITIONS: A summary of the general meteorological conditions existing at function time is given in Table 1.

TABLE 1: Summary of General Meteorological Conditions Existing at Function Time, BW 418, Trials A-3 and A-4

TRIAL NUMBER	DATE (1958)	FUNCTION TIME (MST)	AVERAGE WIND DIRECTION (°)		AVERAGE WIND SPEED (mph)		TEMPERATURE GRADIENT (F°)	
			2 M	125 Ft	2 M	125 Ft	0.5-4 M	0.5 M-150 Ft
A-3	27 Aug	2159	180	188	8.0	14.3	+1.0	+1.8
A-4	28 Aug	2131	151	152	10.4	14.4	+1.2	+6.4

V. CONDUCT OF TEST: These trials were conducted in accordance with the downwind trial procedures outlined in DPG Test Plan DPGTP 418, Phase A.

VI. DISSEMINATION PROCEDURE:

In each trial two aerial spray tanks (especially developed by North American Aviation, Inc.), each containing 20 gallons of BG slurry, were wing-mounted on an F-100A aircraft, and their fills were disseminated concurrently. The aircraft flew at a height of 105 (Trial A-3) and 110 feet (Trial A-4) and at a true air speed of 407 knots. The flight line was 15 miles in length and passed 100 yards upwind from the 300-foot vertical sampling tower located at the vertex of the downwind array (see Fig. 1). Downwind sampling was conducted at a height of 5 feet above terrain for a distance of 15 miles from the vertex of the grid. A summary of the general dissemination data for each trial is given in Table 2.

VII. SLURRY CONTROL ASSESSMENT:

In each trial six representative BG slurry samples were withdrawn during the filling of the spray tanks. Each sample was assayed at three or more serial tenfold dilution levels, and the results of these assessments are given in Table 3.

TABLE 3: BG Slurry Control Assessment Data, BW 418, Trials A-3 and A-4

TRIAL NUMBER	ESTIMATED NUMBER OF VIABLE BG ORGANISMS PER MILLILITER OF SLURRY		
	Mean	95 Per Cent Confidence Limits ($\times 10^{10}$)	
		lower	upper
A-3	1.63	1.55	1.70
A-4	1.60	1.54	1.65

VIII. SAMPLING DATA:

In each trial the sampling was accomplished by means of impingers (AGI 6-15), in series with pre-impingers, emplaced at 5-foot intervals on the 300-foot vertical sampling tower, and at the 72 downwind sampling stations shown in Figure 1.[2] On the tower, each device was activated shortly before slurry dissemination and was aspirated continuously for a period of 10 minutes following the initiation of the spray run. In the downwind array the total dosage and sequential sampling impingers were activated and deactivated in accordance with computed cloud trajectory data provided continuously during aerosol transit by the meteorologist-in-charge.

[2] Station 28, Lateral I, and Stations 2 and 4, Lateral L, were not used.

TABLE 2: General Dissemination Data, BW 418, Trials A-3 and A-4

TRIAL NUMBER	FLIGHT HEIGHT AT TOWER (Feet above terrain)	TRUE AIR SPEED (Knots)	LENGTH OF DISSEMINATION LINE (Feet)	DISSEMINATION TIME (Seconds)	FLOW RATE (gpm) Pre-set Left Tank	FLOW RATE (gpm) Pre-set Right Tank	FLOW RATE (gpm) Calculated Left Tank	FLOW RATE (gpm) Calculated Right Tank	AMOUNT OF SLURRY DISSEMINATED (Gallons) Left Tank	AMOUNT OF SLURRY DISSEMINATED (Gallons) Right Tank
A-3	105	407	76,426	108	8.7	8.7	9.0	8.7	16.13	15.69
A-4	110	407	76,331	111	9.8	9.8	8.4	8.9	15.48	16.43

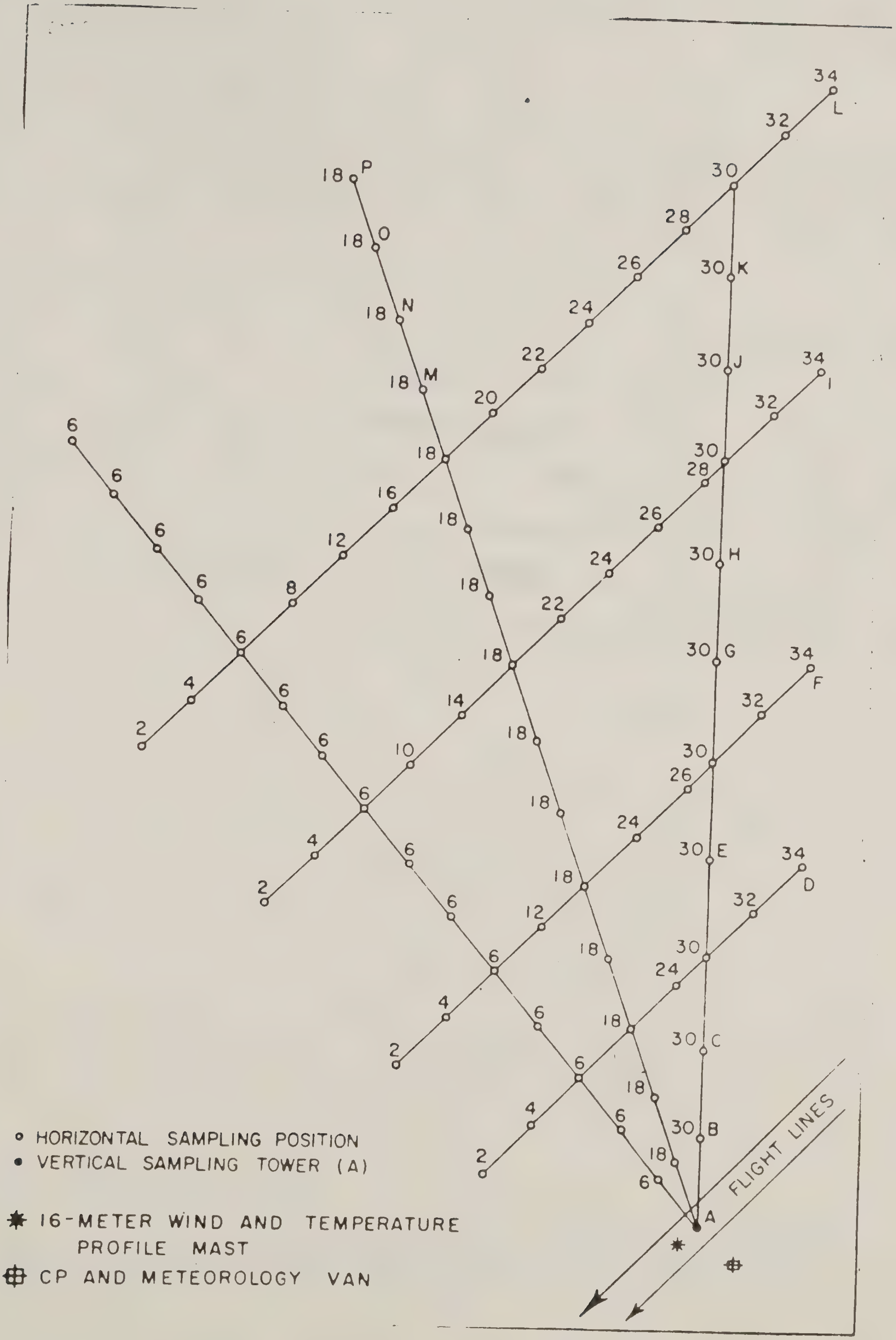

Figure 1.- Diagram showing flight line and sampling array used in BW 418, Trials A-3 and A-4

The impinger recovery of BG organisms on the downwind array in Trials A-3 and A-4 is graphically presented in Figures 2 and 3. All sampling data, both vertical and horizontal, are tabulated in Appendix A.

IX. METEOROLOGICAL DATA: Four wind speed transmitters were installed at the 100-, 150-, 200-, and 300-foot levels on the vertical sampling tower to provide wind velocity data from 50 to 300 foot above ground. The location of the other meteorological stations is shown in Figures 4 and 5. Wind streamline analyses, cloud trajectories, and a summary of the wind speed and direction, temperature, temperature gradient, and relative humidity data collected during the trials are presented in Appendix B. Complete meteorological data are on file at Dugway Proving Ground.

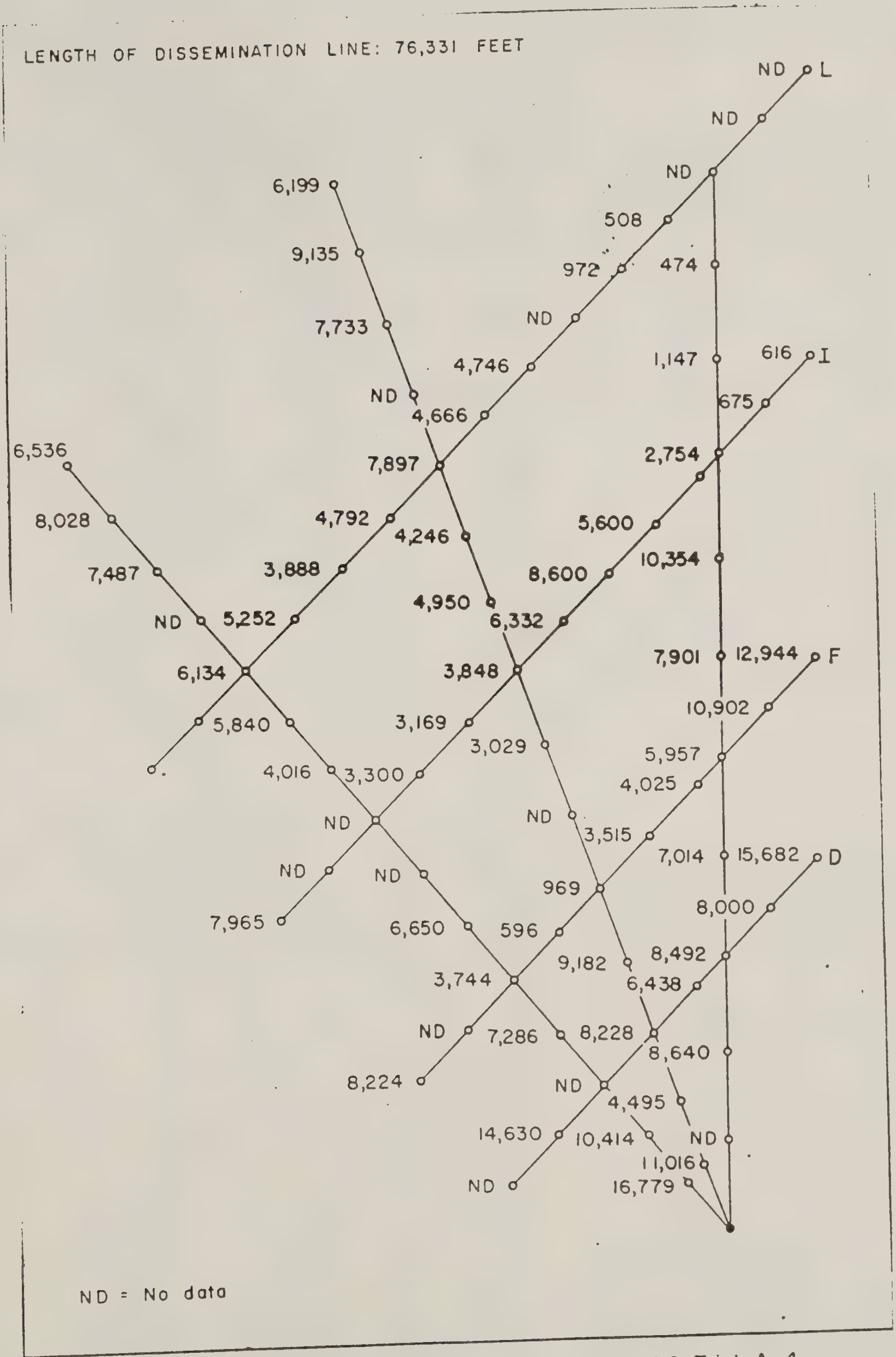

Fig.3.– Impinger recovery of BG organisms, downwind array, BW 418, Trial A-4.

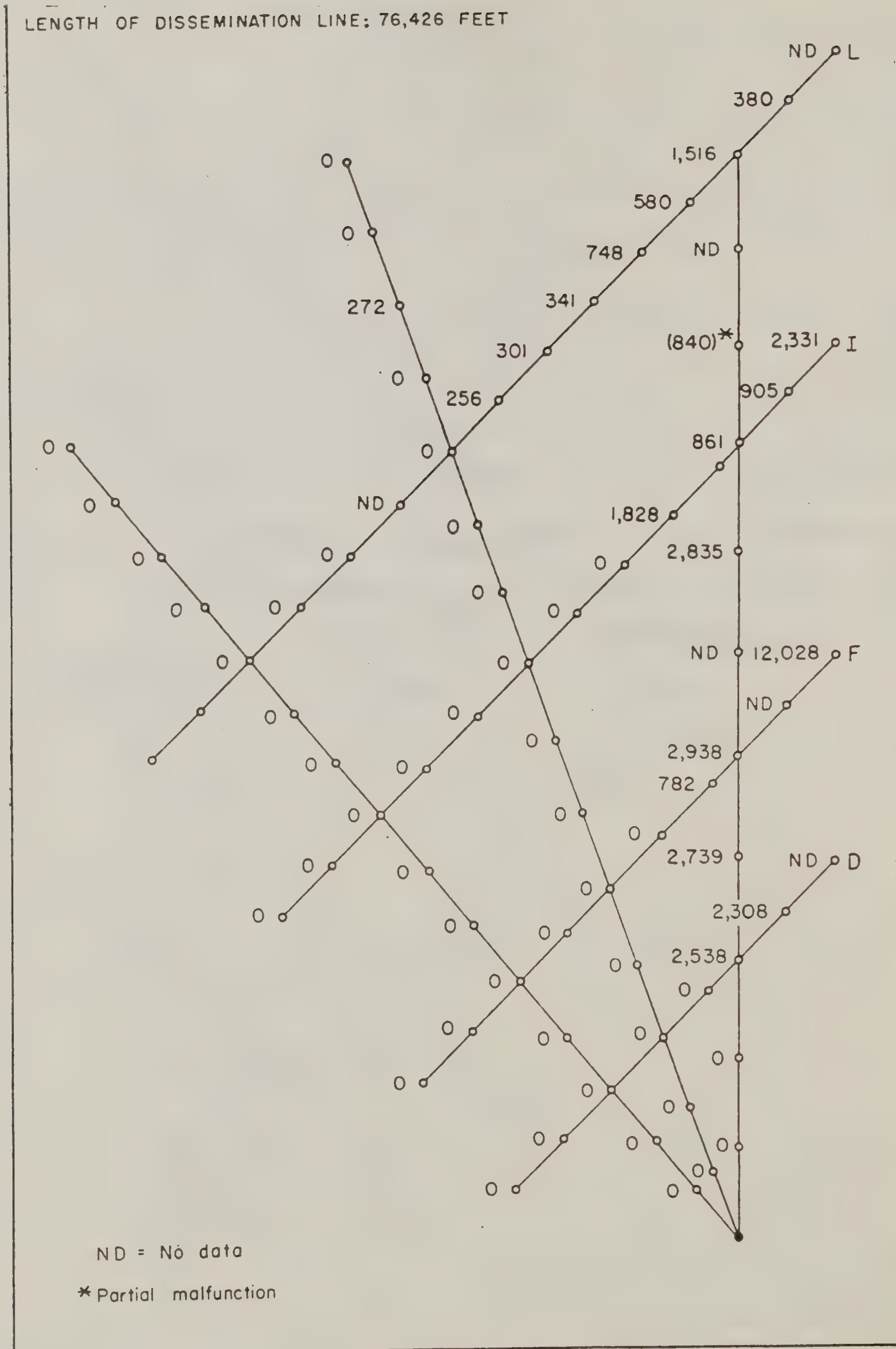

Fig.2.-Impinger recovery of BG organisms, downwind array, BW 418, Trial A-3.

TABLE 1: Vertical Sampling Data, BW 418, Trial A-3

HEIGHT ABOVE GROUND (Feet)	ESTIMATED NUMBER OF BG ORGANISMS COLLECTED		HEIGHT ABOVE GROUND (Feet)	ESTIMATED NUMBER OF BG ORGANISMS COLLECTED	
	Pre-impinger	Impinger		Pre-impinger	Impinger
3	35,888	91,448	78	13,275	11,899
8	43,220	5,511	83	10,350	8,930
13	84,375	123,420	88	9,788	7,864
18	83,250	124,432	93	ND	(6,973)**
23	83,250	106,560	98	6,975	6,082
28	54,562	78,662	103	2,441	4,140
33	34,312	70,148	108	0	0
38	24,637	41,700	113	0	0
43	22,725	45,990	118	0	0
48	14,400	25,560	123	0	0
53	ND*	20,920	128	0	0
58	21,938	17,589	133	0	0
63	13,950	25,358	138	0	0
68	14,440	12,000	143	0	0
73	4,725	8,170	↓	↓	↓
			268	0	0

*No data

**Numbers in parentheses are interpolated values.

TABLE 3: Vertical Sampling Data, BW 418, Trial A-4

HEIGHT ABOVE GROUND (Feet)	ESTIMATED NUMBER OF BG ORGANISMS COLLECTED		HEIGHT ABOVE GROUND (Feet)	ESTIMATED NUMBER OF BG ORGANISMS COLLECTED	
	Pre-impinger	Impinger		Pre-impinger	Impinger
3	0	0	88	2,858	7,600
8	0	0	93	9,225	10,354
13	0	0	98	1,204	4,890
18	0	0	103	2,959	3,464
23	0	0	108	1,485	2,027
28	0	0	113	0	0
33	0	0	118	0	0
38	0	0	123	0	0
43	11,362	8,922	128	0	0
48	6,008	12,485	133	0	0
53	20,588	40,185	138	0	0
58	10,462	15,922	143	0	0
63	31,638	30,525	148	0	0
68	17,212	27,904	153	0	0
73	18,112	31,500	↓	↓	↓
78	8,888	25,968			
83	7,808	8,720	293	0	0

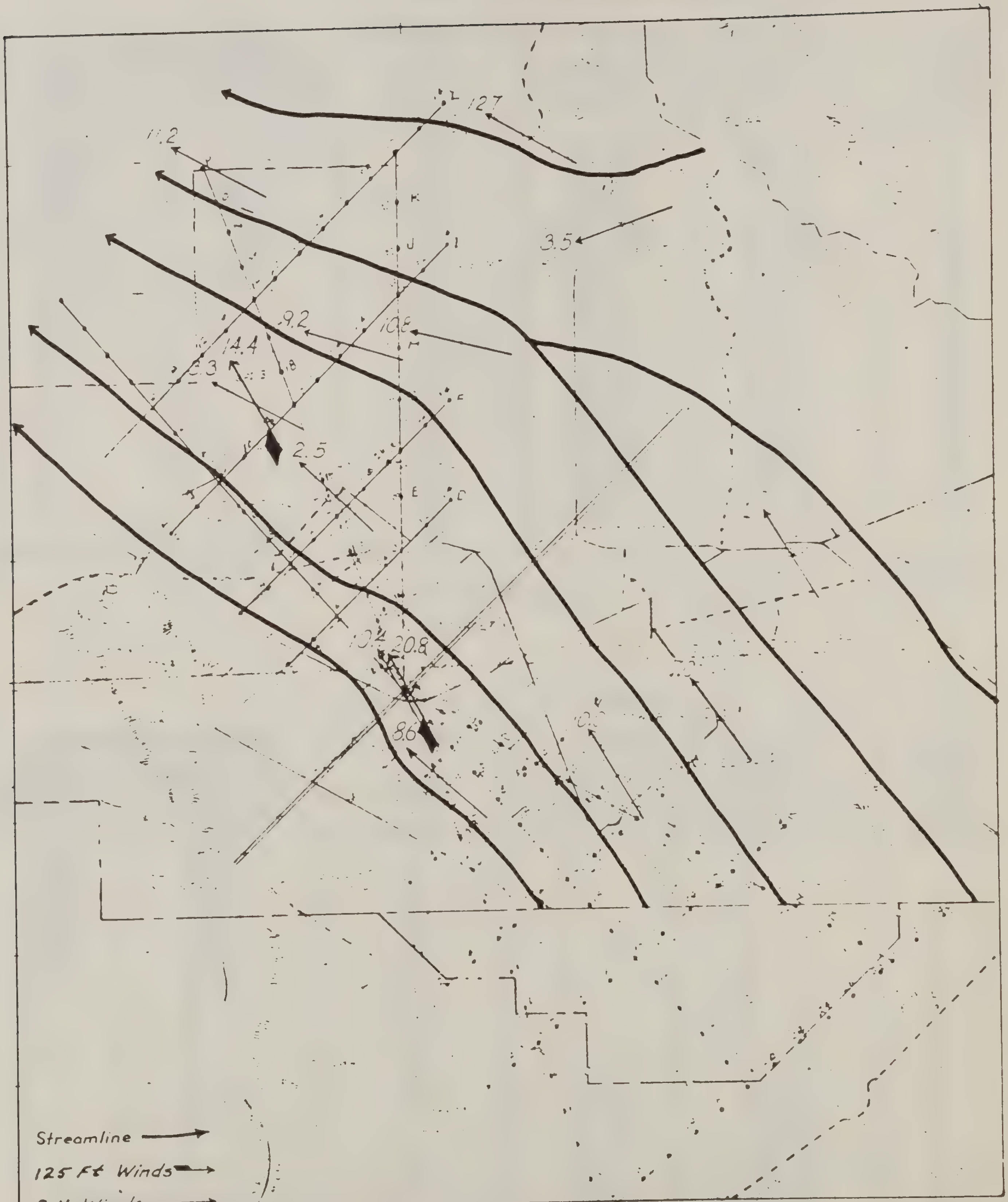

Fig. 11.- Wind streamlines at Z, BW 418, Trial A-4, 28 August 1958.

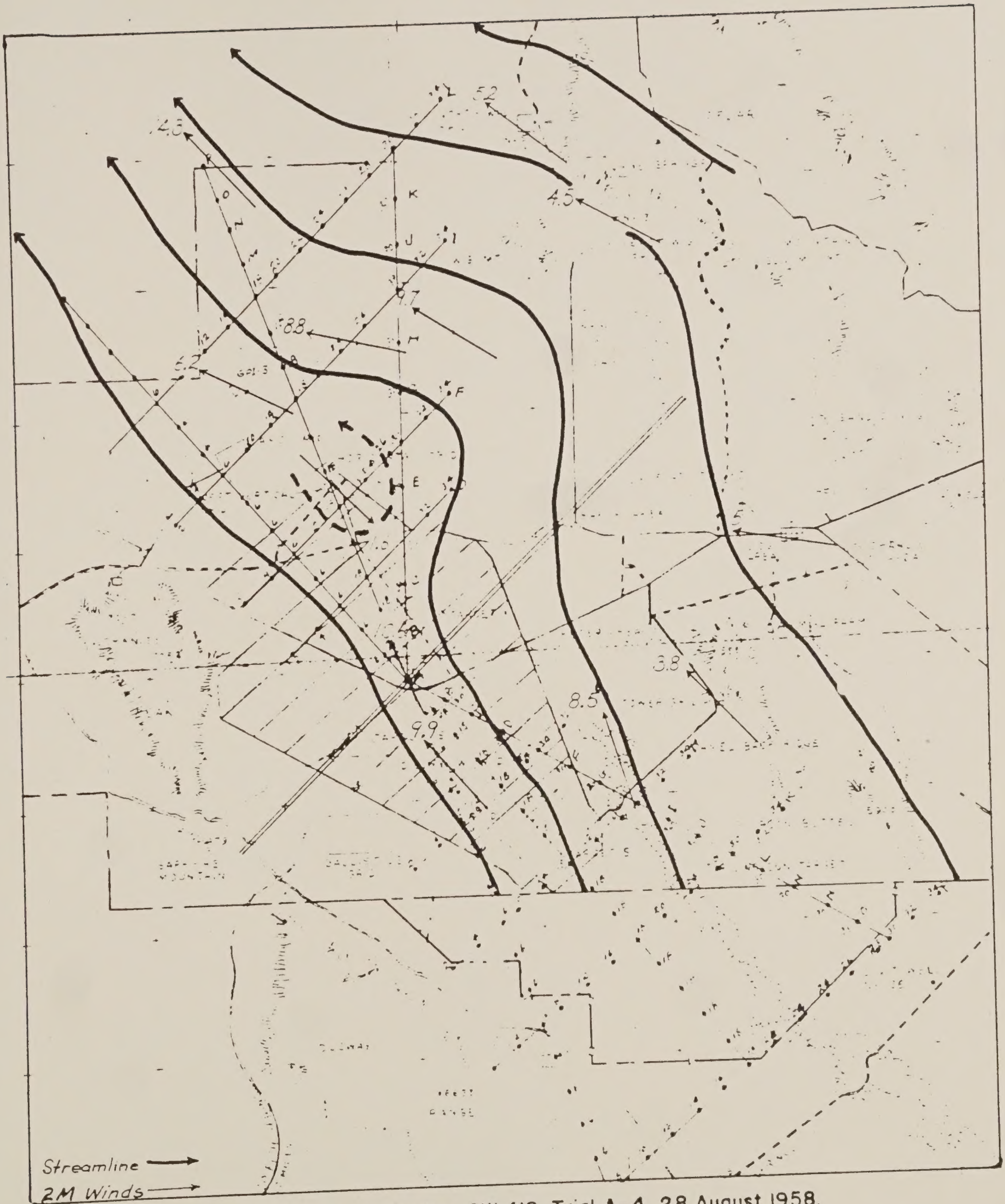

Fig. 12.- Wind streamlines at Z + 15 minutes, BW 418, Trial A-4, 28 August 1958.